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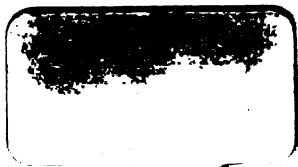
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FROM

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Geo. Butler

W. Henry Butler.

ELEMENTARY PHYSICAL GEOGRAPHY

•The  Co. •



PLATE 1. — FRONTISPICE.

Watkins Glen, N.Y. A post-glacial gorge in a shale rock.

ELEMENTARY

PHYSICAL GEOGRAPHY

BY

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PREFACE.

FOR some time there have been indications that new textbooks on physical geography are demanded; and in the report of the Committee of Ten this finds definite expression. In the preparation of this book, which has been in hand for several years, there is an attempt to meet this apparent demand; but for reasons which are obvious to many, it has not seemed wise to attempt to follow the somewhat radical suggestions which were made by the majority of the geography conference of the Committee of Ten. Therefore, while the physiographic side is given more prominence than is customary in works of this kind, this book attempts to only partly meet the Committee's suggestions.

In the preparation of the book, effort has been made to introduce new material, particularly in the illustrations, which are a prominent part of the book. Also, there has been an endeavor to make the book scientifically accurate, and to introduce the latest knowledge on the subjects treated. There are probably places in which this is not done, for the field is so large that much must be compilation; and the compiler is liable to fall into error.

I anticipate criticism of the order of presentation, of the relative amount of space allotted the various topics, of the

omission of some subjects which are usually found in such books, and of the inclusion of some not usually discussed; but these matters have been carefully considered, and the book is the result of a well-matured plan. In many respects it is experimental, but it is a deliberate attempt to supply a book which is certainly needed. It should not be inferred that the author is satisfied with the attempt,—he is keenly disappointed at the constant necessity of saving space and thereby weakening description and explanation. In many cases, explanations have been omitted; in others, perhaps it would have been better to have done so.

It is hoped that the more advanced teachers will find it possible to accompany the text-book work with laboratory and field study, along the line suggested in the appendix. The discussion of method has been systematically eliminated from the text, and the sole effort has been to present facts and furnish information; but if this alone is put before the pupils, the value of the study will be very slight indeed. It furnishes the main story in a connected way, and supplies certain information; but the laboratory and field will supply applications and extensions of the principles, at the same time giving value to the study as a means of mental discipline. Merely to hear recitations from the book, will be the continuation of an all too prevalent habit, which in so many cases makes the science teaching in our secondary schools the weakest part of the curriculum.

While the author has done much work in some of the subjects treated, particularly the ocean and the land, he would not wish to claim that much in the book is original. In reality, this book is based upon the manuscript of another and more advanced work, which is soon to be published as

a handbook for teachers and for reference. Both of these represent an attempt to gather from all available sources, the kind of matter which it seemed desirable to include in such books. While in the larger work direct reference is made to the sources of information, it has not seemed desirable to do so in this case; for the acknowledgments take much space and distract the attention, without benefiting the pupil.

I have had much generous assistance in the supply of illustrations, particularly of photographs; and grateful general acknowledgment is made here, while special mention of the sources is made in a list in the succeeding pages. Although I have received aid from many sources, there are a few which I must mention especially. The writings of Geikie, Dutton, Powell, and Gilbert, particularly the latter, have not only given me bodies of fact, but also inspiration, as indeed they have to all who are working in physiographic geology. To the writings and teachings of Professors Shaler and Davis of Harvard University, I owe more than I could possibly acknowledge; and to the latter I am under an added obligation for his examination and kindly criticism of parts of my manuscript. While I acknowledge the debt which I owe these scientists, it must be understood that the mode of presentation is my own, and that I alone am responsible for any shortcomings which may appear.

RALPH S. TARR.

ITHACA, N.Y., August 30, 1898.



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- Abbe, U. S. S. S., Annual Report for 1890, Fig. 56.
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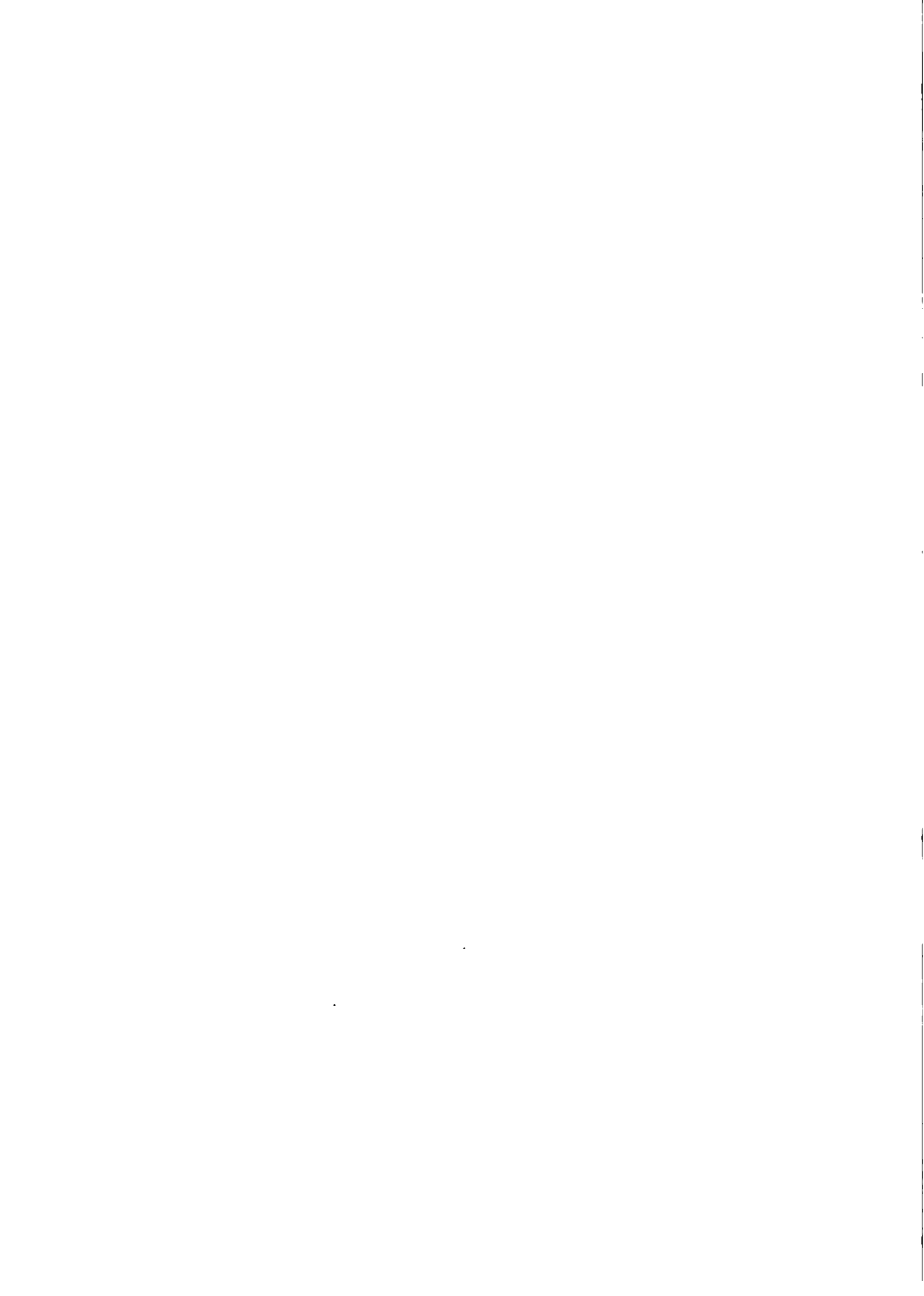
¹ U. S. C. S., refers to the United States Coast Survey; U. S. G. S., to the United States Geological Survey; and U. S. S. S., to the United States Signal Service.

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PART I.

THE AIR.

**WITH AN INTRODUCTORY CHAPTER ON THE ASTRONOMICAL
RELATIONS OF THE EARTH.**

ELEMENTARY PHYSICAL GEOGRAPHY.

CHAPTER I.

THE EARTH AS A PLANET.

Form of the Earth. — The earth is a spherical body composed of three different portions,—a dense central mass, which is probably solid, and two envelopes, the ocean and the air. The central part has a much greater bulk than either of the other portions. In reality the form is not exactly spherical, for the diameters of a sphere should have the same length in all parts; but in the earth the diameter at the equator is $26\frac{1}{2}$ miles longer than that at the poles, where its length is 7899 miles. This flattening of the poles gives to the earth the form of an oblate spheroid instead of a true sphere (Fig. 1).

While this irregularity of the earth was detected only after a series of very careful measurements, it is in reality the greatest on the surface of the earth; but there are other and less extensive irregularities, which are much more noticeable. These are of two kinds,—continents and mountains. The surface rises and falls in a series of great wave-like irregularities, which form the continents and ocean

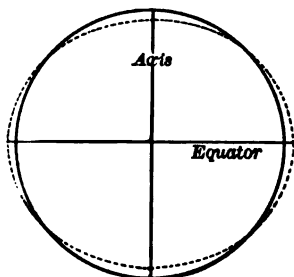


FIG. 1.

Diagram showing a section of a sphere (heavy line), and an oblate spheroid (dotted line).

basins. On the continents, and occasionally in the oceans, the surface rises along relatively narrow lines into a series of high mountain ridges. Although these are the greatest elevations on the earth's surface, and therefore attract our attention, they are really very small irregularities when compared with the continents of which they usually form a small portion (Fig. 128).

Considering the sea level as 0, the highest point on the earth is about 29,000 feet in elevation. Depressions of over 25,000 feet are found in several places in the ocean beds. The total range in elevation between the highest mountain, and the greatest ocean depth is about 57,000 feet. It can be readily seen how small this is in comparison with the earth as a whole, when we remember that the diameter of the earth at the equator is 41,847,192 feet. Upon a globe of ordinary size they could not be shown on true scale. Although there are points on the land whose height is greater than the deepest known parts of the ocean, the average depth of the ocean, which is about 12,000 feet, is much greater than the average height of the land, which is approximately 2500 feet (see Chap. XIV.).

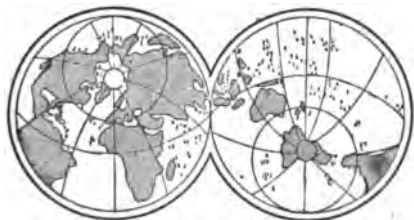


FIG. 2.

Land and water hemispheres.

The greater part of the water on the earth's surface is accumulated in the broad hollows between the continents. The surface of this water mass is much greater in area than that of the land (Fig. 2), the proportion being 1 of land to 2.6 of water (roughly 3:8). Late calculations give the area of the land as 142,000,000 square kilometers, and of the water as 368,000,000 square kilometers. The total volume of

the water of the oceans is estimated to be 1,347,874,850 cubic kilometers.

There are other smaller irregularities on the surface of the earth, and many minor peculiarities, some of which are discussed in the later chapters. Surrounding the earth is a gaseous envelope, the atmosphere, which extends to an

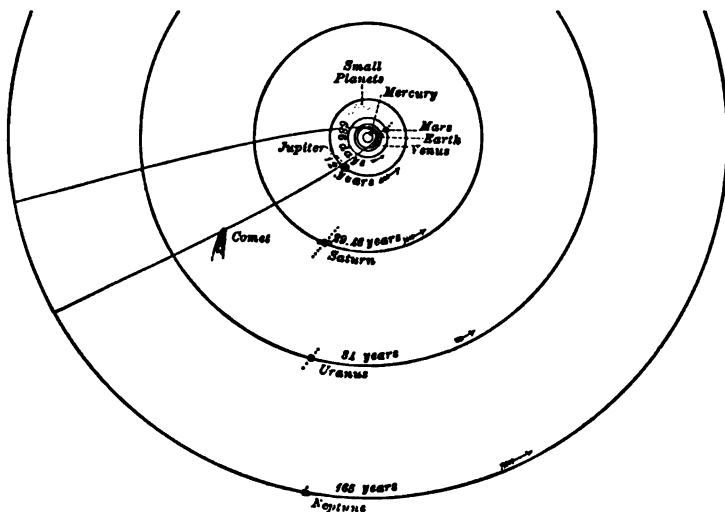


FIG. 3.

The solar system, showing the relative distances from the sun, the direction of revolutions, relative size of the orbits, and the number of satellites.

unknown distance, but which at a height of five or six miles from the surface is very much rarified.

The Solar System.—The earth is one of several bodies which together form the solar system. They are a family of bodies bound together by the tie of gravitation and engaged in a series of movements around a central body, the sun (Fig. 3). In the solar system there are five classes of

bodies. In the center is the sun, the largest of all, and the one upon which the others depend more than upon any other member. The second class of bodies is that of the planets, of which eight are known. These all revolve around the sun in orbits which are nearly circular, but not exactly so, being in reality, ellipses with the sun at one of the foci. The third class of bodies is that of the satellites, of which the moon is an example. Most of the planets have satellites, which are always much smaller than the planet about which they revolve. The earth has but one moon, but some of the planets have several. Twenty moons have already been discovered, of which all but three belong to the outer group of planets, Jupiter, Saturn, Uranus, and Neptune. A fourth group of bodies in the solar system is that of the asteroids, of which about 400 are now known. These small planets revolve about the sun in the space between the orbits of Mars and Jupiter. Aside from these members, there is a fifth group of irregular bodies, the comets and meteors, which move in a manner different from that of the other members of the solar system.

The Sun.—The central and largest member of the solar system, the sun itself, unlike the planets, is so constituted that it sends out into space a form of energy which produces both light and heat. It is the source of much of the energy which finds expression upon the surface of the earth in the forms of light, heat, and life itself. This immense body is fully 92,750,000 miles distant from the earth.

Since the sun is able to emit rays which produce heat, we know that it must be a hot body; but there is as yet no means of telling what its temperature is. Owing to the way it affects the movements of the several members of the solar system, it is known that the materials composing the sun are not so dense as the solid part of the earth. It seems quite

certain that at least a large part of the sun is in the form of gas. By means of the instrument known as the *spectroscope*, we have learned much concerning the actual composition of the sun. By this instrument it has been found that many of the elements known on the earth exist in the sun in a gaseous form.

Since we know very little about the condition of the earth on which we live, it is hardly to be expected that our knowledge of a body so distant as the sun would be very accurate. Still the studies which have been carried on by means of the telescope have revealed the fact that there are at least three quite different parts to the sun. These are the *corona*, which is outermost, the *chromosphere*, and the *photosphere*, the latter being the densest part. It is the portion from which the light and heat are emitted; and from its surface the diameter of the sun is about 860,000 miles (Fig. 4).

Above the photosphere comes the chromosphere, which appears to be the true atmosphere of the sun. It consists mainly of glowing hydrogen gas; but in its lower portions many metals, such as iron, are known to exist in the form of gas. It is in violent commotion, as if in eruption; and the photosphere itself also presents signs of violent activity. Extending to a distance sometimes as great as 300,000 miles above the surface of the sun, is the corona, the character of which is not understood.

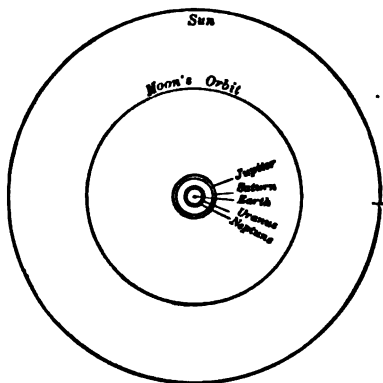


FIG. 4.

Diagram to show the relative size of the sun and the largest planets. Drawn on true scale.

Certain peculiar spots known as *sun spots* (Fig. 5) appear upon the surface of the sun and move across its face until they disappear on the opposite side, being carried around by the rotation of the sun. Their origin is not known, but they appear to have an influence upon the earth in at least two ways, one upon atmospheric electricity, the other upon certain climatic features.



FIG. 5.
Sun spots, 1872.

The sun is engaged in two motions. It rotates, as do all the larger bodies of the solar system; but the period of rotation is not exactly known, though it is somewhere between 25 and 26½ days. Strangely enough, the period of rotation appears to vary according to the latitude. The second motion is one in which the entire solar system is engaged; but the amount and exact nature of this is not known. The system is moving through space at an unknown rate, toward the constellation Hercules.

The Planets.—*Mercury*, the smallest of the planets, is nearest to the sun, on the average being about 35,750,000 miles from it (Fig. 6). The diameter is a little more than one-third

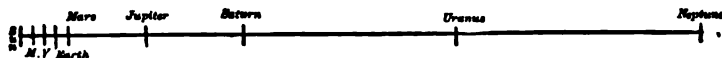


FIG. 6.

Diagram to show the relative distances of the various planets from the sun.

that of the earth (or 2992 miles), and it rotates on its axis in about 24 hours, while it revolves around the sun once in about 88 days. We know little concerning the conditions on this planet.

The next body outside of Mercury is *Venus*, the most brilliant of planets. It is almost the same size as the earth, being in reality about 250 miles less in diameter (7660 miles) (Fig. 7). Some observers think that they have detected a rotation with a period of a little more than 24 hours; but this is doubted by most astronomers. The period of revolution is considerably less than ours, or about 225 days. It appears quite certain that there is an atmosphere upon this planet, and so far as we can tell, it closely resembles ours. No satellite is known to exist.

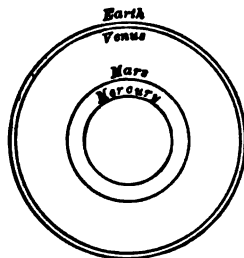


FIG. 7.

Diagram to show the relative size of the smaller planets.

Outside of the earth, which is the next planet in the solar system, comes *Mars*, which next to Mercury, is the smallest of the planets, having a diameter of but little more than 4200 miles. Its time of rotation is a little over $24\frac{1}{2}$ hours, and its revolution about the sun is accomplished in nearly 687 days. Its mean distance from the sun is 141,000,000 miles. The axis of Mars is inclined about 27° to the plane of its orbit, which is about 4° more than the inclination of the earth's axis. There are two tiny satellites, one less than 10 miles in diameter, the other perhaps twice that size; and the latter is not more than 4000 miles from the surface of the planet, about which it revolves in a period of 7 h. 39 m.

Jupiter, the largest of planets (Fig. 4), has a mass greater than that of all the others combined, the mean diameter being about 86,000 miles; but the diameter at the equator is fully 5000 miles greater than that at the poles. The volume of Jupiter is about 1300 times that of the earth. On the average, the distance from the sun is about 480,000,000

miles, and it takes nearly 12 years for it to make a revolution about the sun. The time of rotation is a very little over 9 h. 55 m.

It is evident that what we see with the telescope is not the surface of the planet, but a dense atmosphere of some form of cloud. Therefore we have no means of knowing what the actual condition of Jupiter is, though we may infer that the planet is still heated, and that the clouds which we see are the result of this heated condition. Five moons revolve about Jupiter, the most distant being 1,162,000 miles from the planet, while the nearest is only a little farther away than our moon is from us.

Next beyond Jupiter is *Saturn*, the second largest of the solar planets. Its distance is 881,000,000 miles from the sun, around which it revolves in about $29\frac{1}{2}$ years, while it rotates upon its axis in 10 h. 14 m.¹ This planet has eight moons; but the most remarkable feature connected with it, is its surrounding group of flattened rings, whose inner diameter is 100,000 miles. The telescope has not yet definitely revealed the nature of these rings.

As the distance from the earth increases, our knowledge of the members of the solar system becomes less accurate. Hence, since its mean distance from the sun is fully 1,771,000,000 miles, *Uranus* is scarcely known. It revolves about the sun once in 84 years, but its period of rotation is not known. There are four satellites.

Until 1846 no other large planet was known; but as a result of prediction, *Neptune* was discovered in that year. The discovery of this planet is one of the most remarkable proofs of the accuracy of the theory of gravitation; for it

¹ It will be noticed that as the distance from the sun increases, the time required for a revolution also increases, while the period of rotation rapidly decreases.

was determined by irregularities in the movement of Uranus, that another planet must exist outside of its orbit; and after careful calculations, the place where this planet could be found was predicted, and Neptune was discovered at a mean distance of 2,775,000,000 miles from the sun. One moon has been detected.

Asteroids.—In the year 1801, a small planet known as Ceres was discovered in the space between Mars and Jupiter. Since that time about 400 other smaller bodies have been found in the same general region. In no cases have these *small planets* a diameter greater than 520 miles, while the smallest that have been discovered have diameters of less than 40 miles. Their movement through space is somewhat irregular; and there have been many speculations concerning their origin, though as yet no satisfactory explanation has been advanced.

The Earth.—While cold at the surface, we have many reasons for believing that the interior of the earth is highly heated. Proof of this is found in the facts that at the surface, volcanoes emit quantities of molten rock which come from below, and that in all deep mines and well-borings the temperature of the rocks is found to increase at a moderately uniform rate, on the average 1° for about every 50 or 60 feet of descent. If this rate of increase continues, the rocks at a depth of less than 100 miles are so hot that they would be molten under the conditions which exist at the surface.

It was once believed that the interior of the earth was in a molten condition, and that the solid surface was merely a crust resting upon this liquid sphere; but many facts now lead us to the belief that the interior is at least as rigid as steel. The proof of this has been furnished by the studies of physicists and astronomers. At present we are forced to the belief, that although highly heated, the rocks in the interior

orbit which is nearly a circle; but instead of being actually a circle with the sun at its center, the orbit is really an ellipse with the sun at one of the foci. Therefore, in the course of its revolution, the earth is at one time farther from the sun than in the opposite season, the distance now varying between 91,000,000 and 94,000,000 miles, with an average distance of about 92,750,000 miles.

During the revolution, the earth rotates about one of its diameters, which we call the *axis*, and this rotation occupies a little less than 24 hours (23 h. 56 m.), or one day. This rotation causes the familiar alternation of day and night; and if the earth's axis were at right angles to the plane of revolution, the day and night would be equal in length; but since it is inclined to this plane at an angle of $23^{\circ} 27'$, the relative length of day and night varies from day to day. Indeed, the seasons themselves depend upon this inclination of the poles (Fig. 8); for in the course of a revolution, the pole is always pointed toward a certain part of the heavens; and as the earth moves about the sun, the northern hemisphere alternately faces and is turned away from the sun. When turned toward the sun, the summer season is caused, and when turned away from it, the winter season results, because the solar rays then fall less vertically upon the hemisphere, and the length of the day is shorter. Between these two opposite seasons we have spring and autumn.

The Moon.—This, the nearest to our earth of all the heavenly bodies, has an average distance of about 240,000 miles, and a diameter of 2160 miles (Fig. 9). Since the path of the moon about the earth is an ellipse with the earth at one of the foci, the distance varies; but it is rarely more than 253,000 miles nor less than 227,000 miles distant. When farthest from the earth it is said to be in Apogee,

and when nearest in Perigee; and once in every revolution Apogee and Perigee are reached.

Aside from those it makes in company with the earth, its two important movements in space are a revolution around the earth and a rotation about an axis, both of these movements occurring in the same period of time, or $29\frac{1}{2}$ days. Therefore one side of the moon is never seen from the earth. Also, as a result of this condition, the length of the lunar day is $29\frac{1}{2}$ of our days; and therefore at the lunar equator the sun shines steadily for nearly 15 days and is absent an equal length of time.

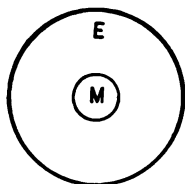


FIG. 9.

The relative size of earth and moon.

Under these conditions the surface of the moon is warmed during the long day, and at night becomes cooled down to temperatures which are perhaps as low as -200° .

There is no atmosphere and no ocean on the moon; and the only change upon the surface seems to be that between conditions of heat and cold, and light and darkness. It emits an almost imperceptible amount of radiant energy, and the light from the moon is reflected sunlight.¹ As a result of the careful telescopic study of the moon,



FIG. 10.

Lunar craters, the largest being Gassendi.

¹ Direct light from the sun is 600,000 times as strong as that which is reflected from the moon.

astronomers have been able to map many of the details of lunar topography, with considerable accuracy, and even to measure mountain heights. While there are other striking topographic features, the most notable thing about the lunar landscape is the great number of crater-like mountains, which bear a certain resemblance to the volcanoes on the earth's surface, excepting that many of them are of immense size (Fig. 10).

Comets, Shooting Stars and Meteors.— Aside from those described, which may be considered the *normal* members of the solar system, there are other heavenly bodies which do not appear to be *regular* parts of the system. The strangest of these are *comets*. Some 500 of these have been recorded as visible to the naked eye; and in addition, over 200 have been detected by the aid of the telescope, some of these being millions of miles in length. When near the sun, they usually have a relatively dense head and a vaporous tail, through which stars are visible (Fig. 11). Some have regular elliptical orbits, and their time of appearance can be closely calculated; but the orbits of others are *apparently* parabolas, so that if they ever return to the solar system, it is only after long periods of time have elapsed, and after having made a journey far beyond the outermost limits of the solar system. Perhaps these may be mere wanderers through space, which after one visit to the solar system, depart never to return again. What they are, whence they came, whither they are going, or what relation they bear to the solar system, is still an unsolved mystery.

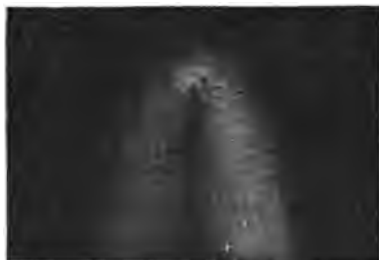


FIG. 11.
Comet of Donati, 1858.

Comets have an added interest to us, from the fact that some *shooting stars* and *meteors* seem to be remnants of comets, which at some former time have crossed the orbit of the earth. Thus the November meteorites are due to the fact that in its movement around the sun the earth encounters particles that are left in the trail of a comet (Tempel's) which has a period of revolution of about thirty-three years; and the August meteors (Fig. 12) appear to have a similar origin.

Meteors and shooting stars (meteors are large shooting stars) enter the earth's atmosphere at a high rate of speed,

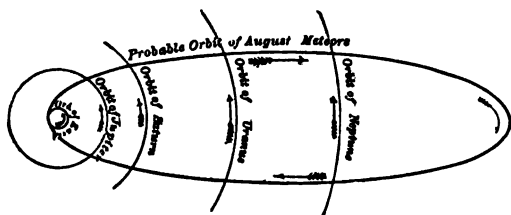


FIG. 12.

Orbit of the second comet of 1862.

and are burned up in the higher layers of the atmosphere, often at an elevation as great as 100 miles from the surface of the earth. This burning is the result of friction

with the air, which produces a high heat, because in addition to the movement of the meteor, there is often added the motion of the earth itself, which is about 98,000 feet a second. Hence in small bodies, the burning is almost instantaneous; but some of the larger meteors pass entirely through the atmosphere, and reach the earth's surface.

A study of these rather rare meteorites, reveals to us the very interesting fact that no new element exists in them; and therefore we may fairly conclude that the elements composing comets are the same as some of those which make up the earth's crust. In watching the heavens at night, scarcely an hour can pass without noticing shooting stars; and since the same would probably be true of the day if we

could then see them, we conclude that there are immense numbers of these bodies in the space through which the earth travels.

The Stellar System.—Far away in space, many times farther than the sun is from us, innumerable stars are scattered. Already many thousands are known, and it is estimated that over 30,000,000 are visible with the telescope. Like the sun, they emit an energy which produces both light and heat; and it is very probable that many, if not all, have planetary bodies revolving about them. One satellite, that belonging to Sirius, has already been discovered; and some double stars are known to be revolving about a common center of gravity. The distance between the stars, and even between the earth and the nearest stars, is immense, and in most cases incalculable. If each star is a sun with accompanying planets, and if each of these suns is as far from its nearest stellar neighbors as we are from ours, the immensity and grandeur of the system transcends our imagination.

The stars are arranged in a disc-like belt, the greatest diameter of which is in the direction of the Milky Way. At right angles to this there is a zone of abundant *nebulae*, (Fig. 13), although these strange bodies are not absent from other parts of the heavens. Some have conjectured that

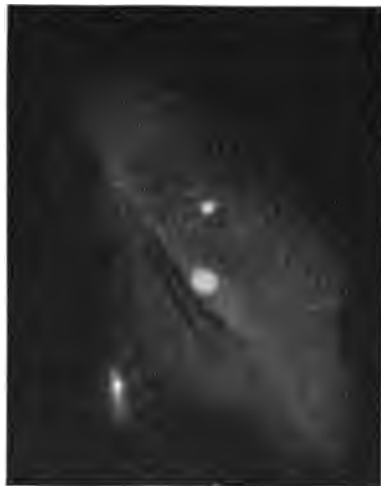


FIG. 13.

Andromeda nebula, from a drawing.

nebulae are other stellar systems, so distant from us that the individual members cannot be separated by our telescopes; but the spectroscope seems to show that they are bodies of glowing gas, and this has an important bearing upon the nebular hypothesis, which we soon discuss. One very important thing concerning both stars and nebulae, is that the spectroscope has detected in them many of the elements which we find upon the earth.

A question of very deep interest, is whether the stars form a great system in which the individual members are inter-related, as is the case among the members of the solar system? Unfortunately, in the present state of science, we are unable to return a definite answer to this question.

Symmetry of the Solar System.—In theorizing upon a basis of known facts we must confine ourselves to the solar system; and it is interesting to note the wonderful symmetry of arrangement and the beautiful order which exists here. Throughout the entire system, the law of gravitation prevails and governs the movements of all the bodies, each member attracting the other in direct proportion to the product of the masses and inversely proportional to the square of the distance. The regular members of the system are all nearly spherical, and they rotate about an axis and revolve in an orbit which is nearly circular. In direction of rotation and revolution there is a marked uniformity, as there is also in the plane of revolution.

All of these regularities of behavior, take place notwithstanding the fact that immense distances separate the various bodies, and that this space is practically void. We can form no accurate conception of these immense distances; but the following quotation from Newcomb's *Astronomy* furnishes some idea of this:—

“To give an idea of the relative distances, suppose a

voyager through the celestial spaces could travel from the sun to the outermost planet of our system in twenty-four hours. So enormous would be his velocity, that it would carry him across the Atlantic Ocean, from New York to Liverpool, in less than a tenth of a second of the clock. Starting from the sun with this velocity, he would cross the orbits of the inner planets in rapid succession, and the outer ones more slowly, until, at the end of a single day, he would reach the confines of our system, crossing the orbit of Neptune. But, though he passed eight planets the first day, he would pass none the next, for he would have to journey eighteen or twenty years, without diminution of speed, before he would reach the nearest star, and would then have to continue his journey as far again before he could reach another. All the planets of our system would have vanished in the distance, in the course of the first three days, and the sun would be but an insignificant star in the firmament."

The sun in the center of the solar system is a true star, in many respects like the others which dot the firmament. This being the case, may we not fairly speculate as to the possibility of other worlds and systems like our own, far away in space, even to the outermost limits which can be reached by the human vision; and if this be so, how vast is the universe, and how insignificant the small cold body of matter upon which we dwell!

The Nebular Hypothesis.— Before many facts concerning the universe were known, the philosopher Kant proposed a hypothesis to account for the origin of the solar system; and later, Herschel and Laplace proposed an explanation which in many respects was like that of Kant. We know this explanation under the name of the nebular hypothesis.

By this it is assumed that the space occupied by the members of the solar system, and probably even to a con-

siderable distance beyond this, was occupied by a nebulous mass of highly heated vapor. It is one of the laws of nature that radiant energy passes from warmer to colder bodies, and that by this radiation a contraction and condensation necessarily follow. This nebulous mass, composed of all the elements which now enter into the composition of the various members of the solar system, during the process of cooling separated into rings which were the parents of the several planets. As the mass lost heat and began to condense and contract, the materials began to accumulate about some denser part of these rings, the accumulations about these denser portions being determined by the fact that gravitational action was stronger there than elsewhere.

As a result of this accumulation about centers, the original nebulous mass became broken up into several smaller masses of similar nature; and by a continuation of the process other rings were thrown off, out of which the satellites were formed. Original motion about a central portion of the nebula has naturally been inherited and is now indicated by the movements of the bodies in the solar system. The cooling of these bodies is still in progress, and different members of the system have reached different stages.

Verification of the Nebular Hypothesis. — While we cannot state that this theory is definitely proven, many facts point to its truth as a general explanation of the solar universe. For instance, it would account for the fact that the planets move about the sun in a common direction, and that the planes of revolution are nearly the same in the different planets (the inclination in no case being more than a few degrees). This similarity also extends even to the satellites; and the rotation of the bodies whose rotation has been determined has the same kind of uniformity. All of the orbits of the members of the solar system are ellipses

approaching a circle. This together with the uniform action of gravitation suggests a common origin.

The fact that all the bodies regularly belonging to the solar system are nearly spherical in form is suggestive; and this form can readily be accounted for if the bodies were once liquid. A former liquid condition is suggested by the fact that those bodies which are well known, all have a larger diameter at the equator than at the poles, although it is true that this may be explained in other ways. Then also, signs of heat are plainly seen in some of the members of the solar system; and in the smaller bodies these signs are less apparent. Thus the sun is highly heated; Jupiter, Saturn, and other of the outer planets show signs of considerable heat; the earth is cold at the surface, and hot in the center; Mars, Venus, and Mercury are cold at the surface; and the moon appears to be entirely cold.

Upon the nebular hypothesis, we should expect that the density of the members of the solar system would increase from the outer bodies toward the center; and this actually is the case, the only exceptions being the easily explained cases of Saturn and the sun. There are other reasons for believing in the nebular hypothesis. So far as we may judge from the results of spectroscopic study and from the examinations of meteorites that have fallen upon the earth, the bodies in the solar system are composed of the same elements as those which make the earth; and this suggests that they have been made from the same original mass.

Far away in space, beyond the solar system, we even find nebulous masses of gas which are exactly like those out of which the solar system is believed to have been made; and in some of these nebulae the condensation into planetary bodies appears to be in progress (Fig. 13). Nearly every gradation has been found between this kind of nebula and

that which is apparently one mass of glowing gas. It is not improbable that even now other worlds are in process of formation in the far distant regions of space.

REFERENCE BOOKS.¹

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- Lockyer.**—**ELEMENTARY LESSONS IN ASTRONOMY.** Macmillan & Co., New York. 8vo. \$1.25. (General and elementary.)
- Chambers.**—**HANDBOOK OF DESCRIPTIVE AND PRACTICAL ASTRONOMY.** Macmillan & Co., New York. Fourth edition, 1889. 8vo. Three volumes. Vol. I., \$5.25; Vol. II., \$5.25; Vol. III., \$3.50. (Large and comprehensive.)
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- Lockyer.**—**THE METEORITIC HYPOTHESIS.** Macmillan & Co., New York, 1890. 8vo. \$5.25. (Suggestion of modification of the nebular hypothesis.)
- Scheiner** (translated by Frost).—**A TREATISE ON ASTRONOMICAL SPECTROSCOPY.** Ginn & Co., Boston, 1894. 8vo. \$5.00.

¹ In giving the publisher's name, the real publishing house is often not mentioned. Wherever possible American houses are given, and since some of these act as agents for European houses, the name of the *agent* will at times appear in the place of the English publisher.

CHAPTER II.

THE ATMOSPHERE.

General Statement.—Outside of the solid earth, and extending to a distance of several hundred miles above it, is a gaseous envelope, which we know as the atmosphere (Fig. 14). Its density decreases from the surface of the earth toward the upper portions; and at a height of five miles it is very much rarefied. That it extends to this great height is shown by the fact that meteors become white hot by friction with it, even at a greater distance than this from the earth. Fully one-half of the mass of the atmosphere is within four miles of the surface of the earth; and two-thirds of it is within six miles of the surface (Fig. 15).

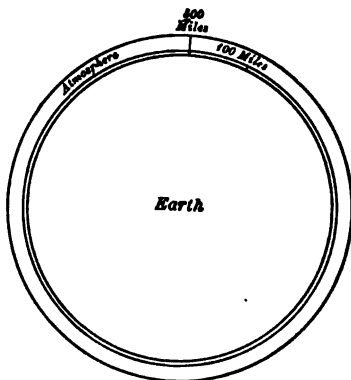


FIG. 14.

The earth with its atmospheric envelope, drawn to scale.

The atmosphere is composed almost entirely of two gases, nitrogen and oxygen, in the proportion of about 79 to 21. These gases are not in chemical combination, but are mechanically mixed. *Nitrogen* is a very inert element, while *oxygen* is active in the production of many changes, and from

this standpoint the nitrogen of the air may be considered as an adulterant of the active oxygen. In addition to these gases there is a comparatively small amount (about 0.03 per cent) of *carbonic acid* gas, the percentage varying somewhat according to the location. Its percentage increases in the vicinity of volcanoes and large cities.¹

Beside these three gases there are minor and variable quantities of other substances; but of these, only two, water vapor and dust particles, are of sufficient general importance for consideration here. The term "*dust*" includes a great

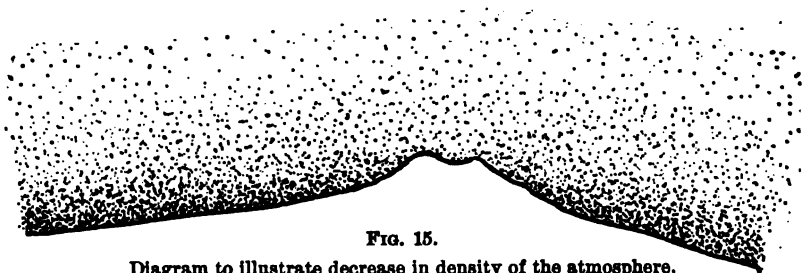


FIG. 15.

Diagram to illustrate decrease in density of the atmosphere.

variety of substances, such, for instance, as microbes, smoke particles, and true dust, which is borne into the air by the winds. It seems certain that dust is of much importance in the formation of rain and fog.

Water is readily evaporated, and hence at all times there is some *water vapor* in the air; but the amount depends upon a variety of circumstances, chiefly the temperature of the air and the presence or absence of bodies of water. With a

¹ While this book is in preparation, the discovery of a new constituent of the atmosphere is announced. This, which is called argon, may be a new element, but it is now too early to state anything definite about this substance.

given amount of moisture, the higher the temperature, the greater the rate of evaporation; but even at temperatures below freezing-point small quantities of water vapor may be present.

The atmosphere is of great importance in many respects. It distributes the light which comes to us from the sun. It is set in motion by the solar energy, and by this means distributes heat over the earth. As a result of the effect of solar heat upon the atmosphere a great variety of phenomena, such as winds, storms, clouds, etc., are produced. These cause many changes upon the surface of the earth, and directly and indirectly the air makes the earth a place fit for habitation.

Light. — We obtain light from several sources, — the sun, the stars, and the moon and planets. Light from the latter source is merely reflected sunlight, and it is small in amount. That which comes from the stars is radiated from them directly, but it also is insignificant in comparison with that received from the sun.

Solar light, when it reaches the lower layers of the atmosphere, produces the impression upon the eye which we know as white; but it has been shown that it probably has a bluish tinge before its passage through the air. According to the undulatory theory, light passes through the space between us and the sun at a very rapid rate in the form of a series of waves of ether. It is made up of many waves of different lengths, the combination of which gives white. When separated, these appear as different colors, and in the rainbow we recognize seven primary colors with intermediate hues. The violets and blues have the shortest vibrations, and the yellows and reds the longest. As a result of the effect of the atmosphere upon these parts of white light many optical phenomena are produced.

If there were no atmosphere, the earth's surface would be

illuminated only where the direct rays of the sun fell. The atmosphere serves to diffuse light and to render the darkness of shadows less intense. This *diffusion of light* in large measure depends upon the amount of solid or liquid impurities in the air. In its passage through the air, certain of the rays are diffused more readily than others by the process of *selective scattering*. It is those rays that have the shortest wave lengths that are thus scattered; and hence it is that the sky is ordinarily blue. The intensity of the blue is greatest when coarse dust impurities are least abundant, as is the case when the air is clear and dry. If dust particles happen to be very abundant, even the coarser rays of yellow light may be scattered; and under rare conditions of very smoky air the entire sky may assume a brassy color. Since the light is obliged to travel through a greater distance of air near the time of sunset than in midday, the color of the western sky in the late afternoon is often yellow, while that of midday was a dull hazy blue (Fig. 16).

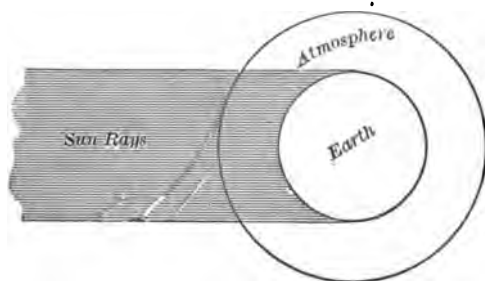


FIG. 16.

Diagram to show that the sun's rays pass through a greater thickness of atmosphere at sunset and sunrise than at midday. (Thickness of atmosphere greatly exaggerated).

Among the most beautiful of light effects in the atmosphere is that of the *sunset colors*, which are due to the scattering of the waves which have the smaller lengths. As a result of this the

coarser yellows and reds come to us, the reason for the scattering being the fact that the light at the time of sunset and sunrise passes through a great thickness of air, and hence the

waves encounter a greater number of dust particles. When the atmosphere contains much dust, the morning and evening colors are often very intense, but an increase in the quantity of dust beyond a certain point tends to dull the tints. With clouds in the horizon at sunset or sunrise, these colors of red and yellow are often reflected in infinite variety of shade and tint. Other phenomena, such as the twilight arch, the glow and the afterglow, are associated with the setting of the sun.

Another property of light is that of *reflection*, and as a result of this many interesting optical effects are produced. The light of the moon depends upon the reflection of sunlight from its surface. The earth also reflects light, and this is one of the reasons for the illumination of places that are in the shadow of the direct rays of the sun. Other places which are illuminated reflect some of their light to the parts that are in shadow. Clouds also reflect the light of the sun; and on summer days, when great banks of clouds rise high in the air, their surfaces are brilliantly illuminated and beautiful cloud effects are produced.

Another effect of reflection is the *mirage*, which occurs when the air near the surface is warmer than the layers above it, and when the reflection from this warm air layer reaches the eye of the observer. It often gives rise to an appearance like that of a sheet of water; and travelers in desert lands, where this phenomenon is common, are often led to think that they are actually approaching a lake. One very commonly sees such an appearance as this at the sea or lake shore when distant coasts appear to rise above the surface of the water. It sometimes happens that light is reflected from a warm layer which is above the observer; and then the objects appear upside down. This "looming," as it is called, is particularly common in Arctic regions; and

the effect produced is so fantastic and wonderful that nearly all Arctic explorers describe it.

The rainbow is a phenomenon which partly depends upon the reflection of sunlight; but it is chiefly due to *refraction*, the result being a separation of the several components of white light into the colors of the spectrum. Each person sees a different rainbow even though two observers may stand side by side. The cause for the phenomenon is the effect of raindrops which, being denser than the air, bend and separate the rays of white light so that we see the component colored rays, just as we do when a sunbeam passes through a prism. A rainbow is often produced in the spray that rises at the base of a waterfall, and at the distance of only a few yards one may see it outlined in the spray.

Another phenomenon resulting from the combined action of refraction and reflection is the ring of light or *halo* which often surrounds the sun or moon when their light passes through thin hazy clouds in the upper atmosphere. These clouds are composed of ice particles, which act upon the light in a manner analogous to the effect of raindrops in the production of the rainbow. Very remarkable halos are formed, particularly in Arctic regions, where the air is often filled with minute crystals of ice. Sometimes rings of light of very brilliant colors are thus produced. The interference with light resulting from the presence of water or ice in clouds often produces a ring of light immediately around the sun or moon. These are called *coronas*, and they are often beautifully colored, the colors being arranged in concentric rings with the red on the outside.

One of the most important of the phenomena of light is that of *absorption*. Many bodies, such as pure air and water, allow most of the rays of light to pass through them with little change, and such bodies are called *transparent*. Other sub-

stances are only partially transparent, and we know them under the name of *translucent* bodies. Still others which we know as *opaque* do not allow any light to pass. Thus objects have a red color when they reflect a greater number of the red than of the other rays; and other colors are produced in the same way by the absorption of different proportions of the rays.

Electricity and Magnetism. — There are certain phenomena of magnetism in the earth which some believe to exercise a decided influence upon the atmosphere. The earth is a great magnet, and the region of greatest magnetic attraction is near Hudson's Bay, toward which the needle of the compass points in our hemisphere. This may be called the *north magnetic pole*. The magnetic condition of the earth is constantly changing, both in small daily variations and in annual changes, as well as in variations covering many years. Occasionally there are magnetic storms, when there is a disturbance of magnetic instruments, and when the *aurora* sometimes develops in wonderful complexity and weird beauty. This is some electrical effect in the thin upper atmosphere; but our knowledge of this phenomenon is obscure.

Electricity is produced in the atmosphere by various causes, and it is nearly always present; but only rarely does it develop sufficient intensity to become visible to the eye. In thunderstorms and tornadoes, when the air is in violent commotion, there is often sufficient electricity to cause vivid discharges from one cloud to another, or to the earth. This *lightning* is an interesting phenomenon, but it does not appear to have an important influence in the formation of the storms, being really a result of them. The accompanying sound is often changed to a rumble by reverberation and echoes among the clouds, and between them and the earth. Often

in violent thunderstorms the air is filled with a constant roar of *thunder*. The lightning spark or bolt is sometimes a single large spark, or it may divide and sub-divide, giving a branching type of discharge; and many interesting irregularities of direction, color, and form are produced.

The light from the flash moves with great velocity while the sound of the thunder travels slowly, at the rate of ordinary sound waves. The sound wave is readily worn out, and at a distance of a few miles lightning produces no perceptible sound. *Heat lightning* is often the result of the reflection among the clouds, or on the horizon, of lightning in some far-distant thunderstorm, perhaps entirely hidden behind the curvature of the earth.

◀**Heat.**¹— Aside from the heat which comes to us from the sun, we obtain a certain small but more constant supply from the other bodies of space and from the earth itself; but these are relatively unimportant. The radiant energy from the sun travels at an enormous velocity as a series of waves, which are radiated out from the sun in all directions; and only that small portion of them is received by the earth which it happens to intercept in its passage about the sun.

Some substances allow this energy to pass through them with readiness, and these are said to be *diathermanous*; others *absorb* it; and still others *reflect* the greater part of the rays that come to them. The air is comparatively diathermanous, as indeed most transparent substances are. The smooth glassy surface of water is a good illustration of a substance that reflects much of the radiant energy coming to it. On the other hand, while the earth reflects some, it absorbs a large quantity of heat; and this is

¹ The sun is emitting a form of energy which under favorable conditions becomes heat, while under other conditions it takes the form of chemical energy. These rays are therefore properly radiant energy until transformed to heat.

particularly true for parts of the earth which are dark in color.

The rays that enter the atmosphere pass through it with little interference, because it is diathermanous; but if there is much dust or water vapor in it, a considerable share of the rays are intercepted. Thus clouds effectually check the passage of many of the rays, and hence cloudy summer days are cool. The same effect is produced by a very hazy atmosphere, and in the late afternoon when the solar rays pass through a great thickness of air (Fig. 16), the amount of heat that reaches the earth is very much less than that which comes to the surface at midday.

Since different parts of the earth's surface behave differently toward the radiant energy, there is much variation in the effect produced. This is particularly well illustrated by the very marked difference in behavior between water and land. The rays that reach the water surface are in part reflected back into space and thus lost, so far as the earth is concerned. Much of that which remains raises the temperature of the water; but as the specific heat of the water is high, its temperature is raised very slowly. Some is used in the evaporation of the surface layers; and in that case the solar rays are transformed to the so-called "latent heat,"¹ which does not become apparent until the vapor is condensed to water. Moreover, the water surface is in motion; and this tends to distribute the heat, and thus to prevent the excessive warming of the ocean surface. Therefore for these various reasons, even at the equator the ocean surface remains relatively cool.

On the other hand, land reflects very little of the radiant energy, and it is a solid body, in which neither evaporation

¹ The old term is still used, though perhaps heat of vaporization would be better.

nor motion is possible. The earth is distinctly not diathermanous, and the greater part of the rays which reach it are absorbed by the surface portions. Therefore during the day the ground tends to become warmed by absorption; and this peculiarity is responsible for many of the phenomena of the atmosphere, which are later described.

Pure air is very slightly warmed by the passage of the direct rays of the sun. The small amount of heat thus obtained is slightly increased by a supply received from the rays which the earth reflects; but much more is obtained from the supply which the earth absorbs. All bodies in space are radiating a form of energy, either that which belongs to them or that which is radiated to them; therefore the earth is at all times emitting rays by *direct radiation*. During the daytime the amount radiated is less in quantity than that received from the sun; but at night, when this supply is cut off, the process of radiation proceeds so far that the earth loses much of the heat which it had received. Radiation is interfered with by the presence of clouds or dust; and hence nights which are cloudy or hazy are warmer than those which are clear.

By the process of *conduction*, all bodies which are warmed tend to transmit their energy to cooler portions. This is well illustrated when a cold iron is placed upon a warm stove. In the same way, the air in contact with the warmer earth is thus warmed by conduction; but neither air nor earth are good conductors of heat, and if this process were unaided, the effect would be slight and confined to those lower layers of the air which were almost immediately in contact with the earth. It is a property of gases that when heated they are expanded and thus made lighter. By this means a process of *convection* is started which bears some analogy to the boiling of water, and the warm lower layers

of air rise above the surface, because the colder and denser air forces the lighter layers to ascend.

The process of convection is one of the most important in meteorology; for upon it in large measure depends the development of the winds and other features of atmospheric circulation. When air rises it expands, and in the process of expansion necessarily cools, the rate of cooling being 1.6° for every 300 feet of ascent; and descending air, as a result of compression, becomes warmed. This feature of cooling on ascension gives rise to the formation of many of the clouds and rainstorms.

Thus the air is warmed, partly by the rays which come direct from the sun; partly by those which are reflected from the earth; partly by those emitted from the earth by the process of radiation; but mainly by conduction from the warm earth's surface and the convectional rising of these warmed layers. Highlands are cooler than lowlands, largely because the air in these places is less dense than that nearer the sea level (Fig. 15). The presence or absence of large bodies of water very markedly modifies the effect of solar energy upon the atmosphere. As a result of these differences, the atmosphere is put in motion, winds are produced, clouds are formed, storms are started, and rains are caused.

The movements of the earth in space also give rise to many variations in heat effect and atmospheric phenomena. As a result of the rotation of the earth, the greater part of its surface is lighted and warmed during a part of every twenty-four hours, and thus we have day and night.

A second important movement of the earth is that of revolution, which causes the seasons (Figs. 8 and 17). Since the pole is inclined to the plane of revolution, the sun is made to appear to migrate in the heavens. During

our winter, when the sun is vertical over that part of the earth which lies between the equator and the tropic of Capricorn, the sun rises in the southern part of the heavens, and passes westward without rising high toward the zenith. Then in Arctic latitudes, the sun does not rise above the horizon; and therefore in this region there is no alternation of day and night. In the winter season, in temperate

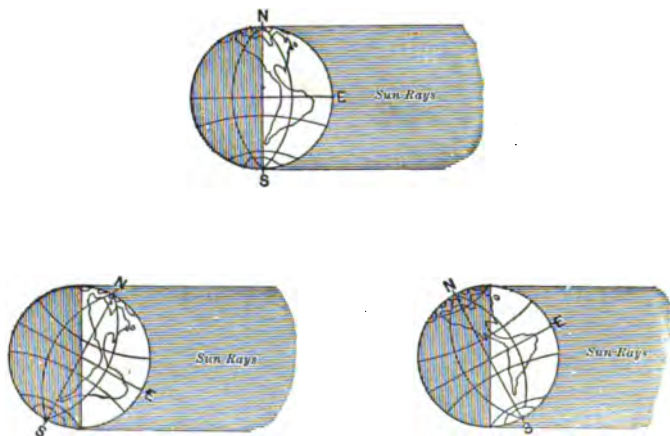


FIG. 17.

Diagram to show the inclination of the sun's rays in different parts of the earth during the various seasons. Upper figure, spring and autumn; right-hand figure, northern winter; left-hand, northern summer.

latitudes the journey of the sun across the heavens occupies a small fraction of the whole day; and therefore in such regions the time during which the earth is receiving heat is less than the length of the night, during which almost none is received.

Besides this fact of short days and long nights, the angle at which the rays reach the surface is much

more oblique than in the summer season; and before reaching the surface they are obliged to pass through a great thickness of atmosphere. These facts make the effect of the small amount of energy that does come, less apparent in winter than in summer, when many of the rays pass from a point near the zenith through a relatively small amount of atmosphere, reaching the surface more nearly at right angles (Fig. 17). After the sun has passed north of the equator, summer comes to the northern hemisphere, while winter prevails south of the equator.

Thus at any point between equatorial and Arctic regions, there are two variations in the effect of the solar rays, one a daily and the other a seasonal variation. The temperature of the air over the land normally rises during the day, and falls at night; it rises in summer, and falls in winter; and the amount of daily rising and falling is greater in summer than in winter. There is much variation in these respects according to latitude; and there is less change in temperature between day and night, and between seasons, at the equator than in most other latitudes; but the *amount* of heat received there is greater than in other parts of the earth. The greatest range in temperature, both seasonal and daily, is experienced in the higher latitudes. The least heat supply is received in polar latitudes; and here there is a great range between the summer and winter temperatures, but slight daily ranges, because in winter the sun does not rise above the horizon, while in summer it does not set.

✓ **Moisture.**—When rays of radiant energy enter a water body, they are in part transformed to “latent heat,” being engaged in the process of changing the liquid to a gaseous condition. By this process of *evaporation* much of the energy exists in a form which is not apparent as heat so

long as the vapor condition lasts; but when the vapor is condensed, this store of heat becomes apparent. Evaporation will take place even from a snow surface; but the most favorable conditions for the production of water vapor are warm air in contact with a water surface.

The capacity of the air for water vapor is limited; and when no more can be contained it is said to be *saturated*. When there is little vapor in the air it is constantly capable of taking more until the limit of saturation is reached. We commonly say that dry air can *absorb* vapor.¹ If the amount of water upon the land is slight, the air in these places remains dry; but naturally this cannot be the case with air over bodies of water, for there the conditions favor saturation. In the interior of continents, and in the upper layers of the atmosphere, there is the smallest proportion of water vapor. If the air from these places reaches the oceans, it may bring to them conditions of dryness, which, however, are soon changed to relative dampness. With the air in movement, saturation is less liable to occur than would be the case if the air were quiet. Therefore winds favor evaporation by bringing fresh supplies of air, and for the same reason they tend to prevent saturation.

The capacity of air for water vapor also depends upon its temperature. A layer of air which is saturated at the temperature of 50° becomes relatively dry if its temperature is raised to 90°; and an air layer which is nearly saturated at 90° will be obliged to give up some of its water vapor if the temperature is lowered a number of degrees. This is a very important point in the formation of clouds, storms, and rains. The *actual amount* of water vapor in the air represents its

¹ Strictly the air does not absorb vapor, but the water vaporizes regardless of the presence of the air. However, it is convenient to speak of the capacity of the air for water vapor, especially as the air determines the temperature.

absolute humidity; but this is not a very important factor, because the same amount of vapor in air of different temperatures will produce very different effects.

The point of greatest importance is the *relative humidity*, which is the percentage of water vapor *actually* contained in the air compared with the amount which the air at that temperature *could* contain if it were saturated. Thus the relative humidity of saturated air at a temperature of 60° is 100 per

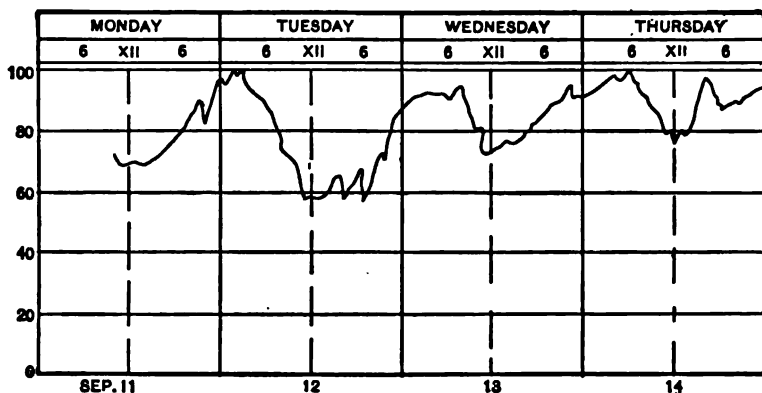


FIG. 18.

Diagram showing daily change in relative humidity as a result of the daily change in temperature at Ithaca, N.Y.

cent, for at that temperature no more can be contained; but if the temperature is raised a few degrees, the air becomes capable of containing more water vapor, and the relative humidity is then less than 100 per cent. The temperature at which air containing a given amount of moisture becomes saturated is known as the *dew point*, for then vapor must be condensed. After a warm and apparently dry day, dew may be formed at night merely by lowering the tempera-

ture of the air, and thus increasing the relative humidity, without any change whatsoever in the absolute humidity (Fig. 18).

It follows from this that there must be very marked differences in the amount and effect of water vapor contained in the air. Over the oceans, the relative humidity is great, and the air nearly always near the point of saturation; in the tropics, where the temperature is high, the absolute humidity is high, because warm air can contain much vapor; and on

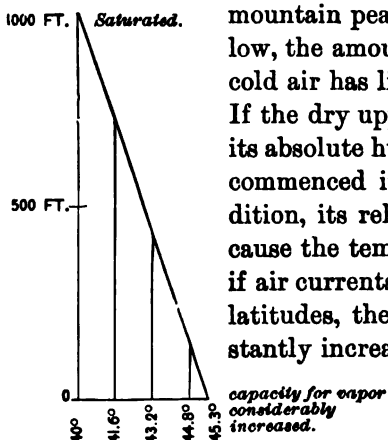


FIG. 19.

Diagram illustrating increase in temperature of descending air. Starting in a saturated condition with a temperature of 40° at 1000 feet, it reaches the surface with a higher temperature and its capacity for vapor increased, while its relative humidity has decreased. The reverse takes place with ascent.

convection, the relative humidity is also increased, because air cools by expansion as it ascends; and under such conditions the vapor is often condensed in clouds and rain.

As a result of these varying conditions we get many variable phenomena. Where the winds are prevailing dry, and

mountain peaks, where the temperature is low, the amount of vapor is slight, because cold air has little capacity for water vapor. If the dry upper air descends to the earth, its absolute humidity is low; and even if it commenced its descent in a saturated condition, its relative humidity decreases because the temperature rises (Fig. 19); and if air currents move from cooler to warmer latitudes, their capacity for vapor is constantly increasing, because they grow constantly warmer and have a greater power of absorbing vapor. When they move

from warm to cooler regions their relative humidity increases, because their temperature descends; and when air rises over land elevations, or vertically by

the relative humidity low, desert conditions result; and where moist winds rise over rapidly ascending lands, conditions of excessive rainfall are produced. With air prevailingly dry, evaporation is rapid, while in regions of great relative humidity, evaporation is slow and small in amount (Fig. 60). Since water vapor contains a store of "latent heat" great stores of heat energy are transported from one latitude to another by the movements of vapor-laden air currents.

Pressure. — The air, though so light and apparently almost without substance, actually has weight. At the seashore, the average weight of the air column is 15 pounds to the square inch; but as we ascend into the air, whether in a balloon or on a mountain, the pressure of the air becomes less and less. Aside from this difference in air pressure the weight of the column of atmosphere at any single point is almost constantly changing. This is due to the fact that the air is very elastic and is subjected to a complicated series of movements. We shall be better able to understand the causes for these changes in pressure, and their effects upon the atmosphere, after we have examined in more detail the subjects of air temperatures and circulation.

Effect of Gravity. — In a measure heat and gravity are in conflict in their effect upon the air. Heat is always expanding, some portions more than others, but gravity in trying to hold the air to the earth attracts the cooler and therefore denser parts more strongly than it does the lighter warmed portions. This starts a movement of the air, for the denser portions are drawn down to the surface and the lighter parts pushed above it. Gravity is thus a most important factor in determining the equilibrium of the atmosphere; for its constant tendency is to restore an equilibrium which other causes are tending to destroy.

Effect of the Earth's Rotation. — As the air moves in the form of winds or currents, there is a constant tendency to

be deflected to one side, as a result of the effect of the earth's rotation. This not only tends to turn the currents of air, but its influence is also felt in the ocean currents.

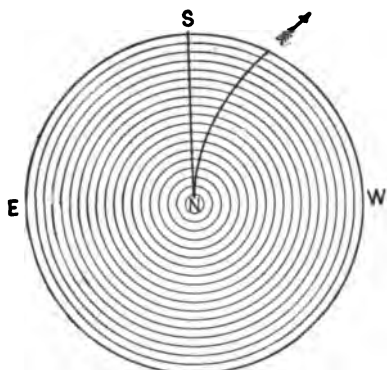


FIG. 20.

Diagram to show how the moving currents are deflected from a straight line N-S.

In the southern hemisphere the currents are deflected toward the left, and in the northern hemisphere toward the right; and we commonly speak of the latter as the right-hand deflection (Fig. 20).
By revolving an orange or a ball around an axis, one can see that the motion at the equator is much more rapid than that at the poles. Each revolution carries every point along a circle, but the diameter of the circle decreases toward the pole (Fig. 21). Therefore in the course of a revolution a point near the equator travels a much greater distance than one near the pole. To do this, it must go faster, since the same period of time is allowed for revolution in any latitude. At the equator the rate is 1521 feet a second, while near the poles the rate is greatly reduced.

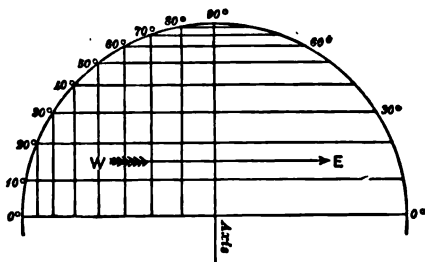


FIG. 21.

Diagram illustrating the decrease in diameter on different latitudes.

A body, no matter what its direction of movement (north,

east, south, or west), upon moving over the surface of a rotating sphere is constantly subjected to deflection, toward the right in the northern, and the left in the southern hemisphere. The amount of this deflection depends in part upon the velocity of the moving body, a rapidly moving current being less deflected than one with slow movement. It is, moreover, more decided in the higher latitudes than near the equator, reaching a minimum at the equator.

So a body, such as a current of air or of water, moving southward in the northern hemisphere is turned to the right at a rate which will vary with its velocity and with the latitude. Hence it becomes turned toward the west. If the movement be toward the north, the right-hand deflection turns the body toward the east. In the southern hemisphere the turning is just opposite. That is to say, a body moving northward, or toward the equator, is turned toward the left or the west, and if moving away from the equator it is turned toward the left, or the east.

Unfortunately the reason for this important principle seems incapable of clear non-mathematical expression; at least, all such explanations known to the author are either mathematical, or incorrect or obscure. It therefore seems best for the present to leave the matter with a mere statement of the fact.¹ The fact, however, should be clearly understood, for upon it depends much of the matter which follows. It will be seen that the ocean currents and winds are thus deflected; and upon this depends many peculiarities of climate in various parts of the world.

¹ The teacher will find the subject fully discussed in Ferrel's *Popular Treatise on the Wind*, referred to on page 84. A simple experiment illustrating the principle may be tried by means of a circular table top which can be revolved. A marble dipped in ink, and allowed to run over the revolving table, will be deflected from a straight course in a direction varying with the direction of rotation of the table.

REFERENCE BOOKS.

See also references at the close of Chapters III.-VII.

- Davis.** — **ELEMENTARY METEOROLOGY.** Ginn & Co., Boston, 1894. 8vo. \$2.70. (Almost all points thoroughly treated in the light of the best modern knowledge.)
- Loomis.** — **TREATISE ON METEOROLOGY.** Harper Brothers, New York, 1870. 8vo. \$1.50.
- Scott.** — **ELEMENTARY METEOROLOGY.** Scribner, New York (Agents). Fifth edition, 1890. 12mo. \$1.75.
- Tait.** — **LIGHT.** Macmillan & Co., New York (Agents). Second edition, 1889. 8vo. \$2.00.
- Capron.** — **AURORÆ.** E. & F. N. Spon, New York (446 Brown St.), 1879. 4to. \$17.00.
- Guillemin** (translated by Thompson). — **ELECTRICITY AND MAGNETISM.** Macmillan and Co., New York, 1891. 8vo. \$8.00. (Much on atmospheric and terrestrial electricity and magnetism.)
- Maxwell.** — **THE THEORY OF HEAT.** Longmans, Green & Co. Tenth edition. (Edited by Lord Rayleigh.) 1892. 12mo. \$1.50.
- Tyndall.** — **HEAT AS A MODE OF MOTION.** Appleton & Co., New York. Fourth edition, 1883. 12mo. \$2.50.

In most good books on physics, the subjects of heat, light, and electricity are well treated from the physical standpoint.

The American Meteorological Journal (monthly, Ginn & Co., Boston) contains a record of the progress in the subject, and many original articles of general interest. \$3.00 a volume; eleven volumes published. The publication of this magazine has now (May, 1896) been suspended; but in the various published volumes there is much of value.

CHAPTER III.

DISTRIBUTION OF TEMPERATURE.

General Statement.—If nothing were present to interfere with or to distribute the solar rays that come to us, we should have a very regular distribution of heat over the earth's surface. At the equator the temperature would be extremely high, much higher than at present; in the Arctic latitudes there would be very low temperatures; and between these two belts there would be intermediate conditions. In each of these belts there would be seasons, and the difference between the day and night as at present. This theoretical distribution of the solar heat is in reality so well defined that we are able to divide the earth's surface into three great climatic zones,—the Arctic, Temperate, and Tropical belts (Fig. 65).

In each of these zones there is a regular normal variation in the temperature of the different seasons, there being a gradual rise from winter to summer which with the corresponding descent from summer to winter makes what we may call the seasonal range or curve (Fig. 24). By the rise of temperature during the day, and its fall at night, a daily curve is also produced (Figs. 22, 27–29, and 33); and therefore the seasonal curve is made up of a large number of daily curves (Fig. 23). Theoretically, these should all be regular, and season after season we should have an almost exact repetition of these curves. However, in reality, this is far from being

the case; and the divergence from the theoretical is due to the presence of a number of disturbing influences. These are (1) the effect of atmospheric movements, (2) the influence of the oceans, or the absence of such influence, (3) the effect of topography.

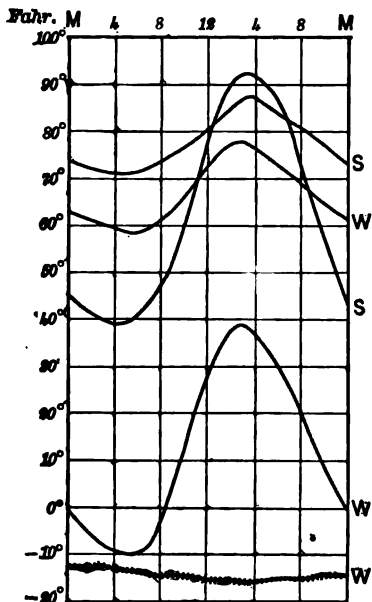


FIG. 22.

Daily temperature curves. Lowest, Arctic (winter); second, north temperate land interior (winter); third, same (summer); fourth, sea coast near the tropics (winter); fifth, same (summer).

Effect of Atmospheric Movements.—This subject is again referred to in the chapter on winds, and now we need only consider a few of its general features. There is a *regular* circulation of the atmosphere, and numerous other movements which we may call *irregular*. Certain winds blow with moderate steadiness toward the equator, where the air rises and then flows away at a considerable elevation above the earth's surface. By this means much of the heat which reaches equatorial regions is borne away and distributed in other zones. In the north temperate latitudes the general movement of the atmosphere is toward

the east; and this brings to west coasts the warm air from over the oceans, while to the eastern parts of continents, air is brought from the interior regions. By means of these and other general influences of the atmospheric circulation, the temperature of the earth's surface is greatly modified.

Smaller movements do locally what these great movements do in a general way. Thus a storm passing across the country brings conditions of cloudiness and rain, and produces winds which are sometimes warm and sometimes cold. By this means air is sometimes drawn from cold, snow-covered lands; or it settles from the upper cold layers of air; or it may be drawn from the equable ocean. At the seashore, during the summer, the cool sea breeze may blow and modify the heat of the hot summer day (Fig. 88).

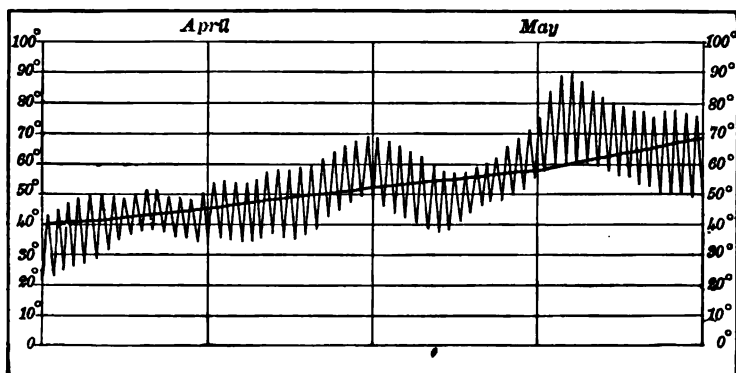


FIG. 23.

Diagram illustrating mean seasonal rise in temperature, with daily and irregular changes superimposed.

Influence of Oceans.—The ocean, and even large bodies of fresh water, are important modifiers of climate. As we have already seen, the ocean water warms very slowly, and it cools with almost equal slowness. Therefore the difference between the temperature of day and night, and summer and winter, is much less there than on the land, which warms rapidly during the summer day and cools readily at night and in winter. Over the ocean, in tropical latitudes, the

temperature range throughout the year is very slight; and in temperate latitudes, while the range is much greater than this, it is still small compared with the range on the land (Fig. 24). Therefore near the seashore, the temperatures of the summer and the day are relatively low, while the temperatures of winter and the night are relatively high. Even on the shores of small lakes this influence of water is noticeable.

On those coasts which are reached by prevailing winds from the ocean, as on the west coast of the United States, the general temperature is high, and the climate equable. Even in a short distance the temperature difference may be very marked; and while *on* the shore the effect of the ocean is plainly felt, this influence becomes very much less marked at a distance of a few miles from the coast.

Another very important influence of the ocean is that caused by the fact that this body itself is in motion. Both warm and cold ocean currents move on the surface of the sea and tend to equalize the temperatures of different parts of the earth. By this circulation, lands that would otherwise be uninhabitable have their climate rendered much more equable than that of regions in lower latitudes where these conditions of oceanic circulation do not exist. One of the best illustrations of this is the difference between the climate of Western Europe and Eastern America.

As a general statement it may be said, that under the present conditions of distribution of land and water, ocean and air circulation, and alternation of day and season, the general climate of the globe becomes progressively colder as the polar regions are approached; and as we pass from the seashore toward the interior of continents, we go from regions of equable climate, to those possessing great ranges in temperature between the winter and summer, and day and night.

Effect of Topography.—It would be quite impossible to enter into this subject in much detail. In general, valleys are warmer than hilltops, partly because they are protected from the wind, and partly because the solar rays that fall upon the valley sides are in some degree reflected into the valley. The sides of hills, or of mountains which face toward the sun, are warmer than the north-facing sides; and this is often very well shown in the natural distribution of plants, which rise higher on the southern side of the hill than on the northern side, where the temperature is less favorable to their existence (Fig. 68).

Next to latitude, *altitude* is probably the most important feature in determining climate. If the elevation be sufficient, conditions in some respects resembling those of the Arctic climate may be found even under the equator. At a height of from 15,000 to 18,000 feet above sea level, vegetation ceases to exist, and perpetual snow covers the mountain tops. This is due to several causes, the most important of which is the fact that the air at great elevations is less dense (Fig. 15), and hence cooler. Through this relatively thin layer, which is clear and free from large quantities of dust particles and water vapor, the rays that fall upon the surface are readily radiated into space.

This illustration is interesting, since it shows that in the same latitude, and consequently with the same *amount* of solar energy, the two opposite extremes of tropical and Arctic climates may result. It brings out very strongly the fact that the mere *amount* of energy received does not determine the *temperature* of a place; the subsequent behavior of this is equally important. This same fact is shown by the difference between the climates of the sea-shore and the land at different places in the same latitude.

Almost everywhere on the earth the influence of topog-

raphy upon temperature is shown, sometimes in great differences extending over wide areas, again very locally and in small amount. Mountain ranges prevent the passage of vapor-laden air into the great enclosed basins, where dry clear skies exist, and where desert conditions are consequently produced; and we might find many instances, great and small, to illustrate the influence of land forms upon the distribution of temperatures.¹

◁ **Seasonal Temperature Range.**—From the above, it is seen that latitude is no true indication of temperature; for it is but one of several factors which tend to determine climate. However, it is one of the most important of the factors, and in general the temperature decreases from the equator toward the poles. Still, owing to the disturbing influence of the other factors, this decrease is not regular; and hence the lines of equal temperature, or the isotherms, are not parallel to the lines of latitude, but often diverge very widely from them. If we examine the charts of isotherms (Plates 2, 3, and 4), we find that they are irregular, and that the irregularities vary with the season. Moreover, any given line, such for instance as the 50° isotherm, is in a different place in the opposite seasons. In other words, the temperature of every part of the earth changes with the season; but the change is different in amount in different places.

This seasonal change may be called the temperature range or curve. If the temperature changes of any given region are plotted upon a diagram, in which both the months and the scale of degrees are shown (Fig. 24), we find that there is a gradual rise in the spring to a time after midsummer, when the temperature falls until after

¹ Many of these features are illustrated in the accompanying isothermal charts.

midwinter. Year after year this is true, though each year will show a slight difference from those which precede and follow. Even in different regions the same is shown; but there is much variation in the form of the seasonal curve of different places. Such a curve shows how much difference there is between seasons, and when it occurs. We find that the *height* to which the temperature rises

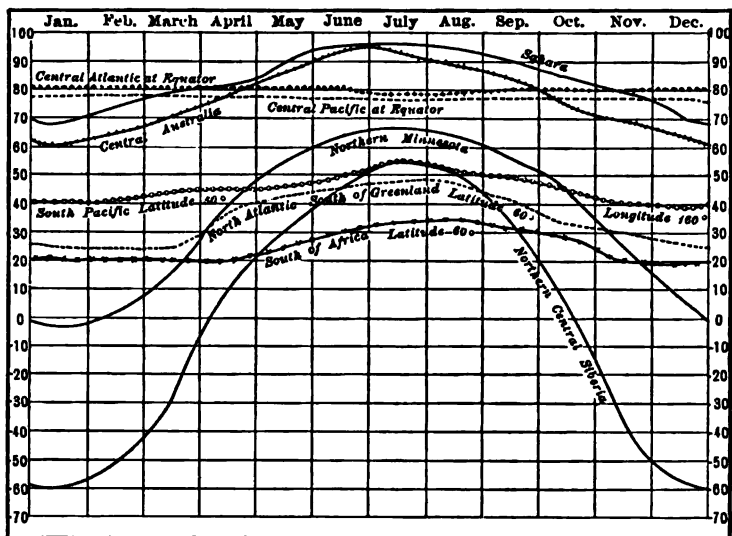


FIG. 24.

Seasonal temperature ranges. Constructed to have northern and southern summer coincide. Hence for southern hemisphere June should read January, etc.

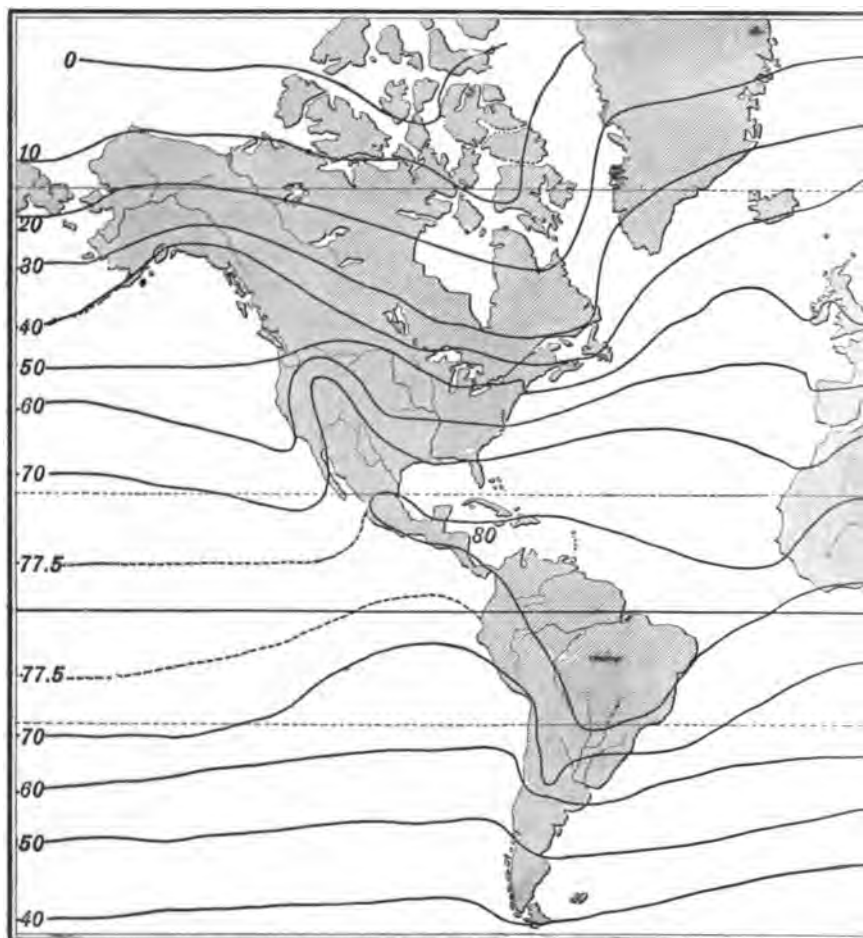
in the curves is very variable in different parts of the earth, and the same is true of the *length* of the warmer or the colder part of the curve, which is the same as saying that the length of the warm season differs in different places.

If we plot such a curve as this for a place over the ocean, we find that it is relatively flat, because the difference between the winter and summer temperatures is not very

great. On the other hand, in the central parts of continents, where the winter is relatively cold, and the summer warm, the curve rises to a much greater height. At the equator, the curve is much flatter than in temperate and Arctic latitudes, where the difference between summer and winter temperatures is great. In any one of these zones there may be marked differences even in neighboring places.

Upon examining one of these seasonal curves, it will be noticed that the time when the temperature is highest does not correspond with the period when the greatest amount of heat is received from the sun; nor is the coldest time of winter coincident with the shortest days. In other words, there is a lagging, and this is due to the cumulative effect of the heat or cold. In the early summer, the ground is still cool from the effects of the last winter, and in high latitudes there is still snow upon the ground. It takes some time for the sun's rays to warm the ground and the air; and when this is done, the effect of solar energy becomes greater than before, even though the days be shorter and the amount of energy coming from the sun less than in mid-summer. In the opposite season, the effect of radiation during the long nights becomes most marked after the middle of winter, which is really the 22d day of December. Therefore January is almost invariably colder than December, and February also may be colder than December.

For the sake of diagrammatic illustration, the seasonal curve is represented as being a continual rise and fall of temperature. It represents the *average* temperatures for the several parts of the different months. In reality there is no such regular and uniform rise, but it is interrupted by daily risings and fallings (the daily curve, pp. 60-62), and by irregular interruptions (Fig. 23). For days at a time the normal seasonal rise or fall may be interrupted, and even be



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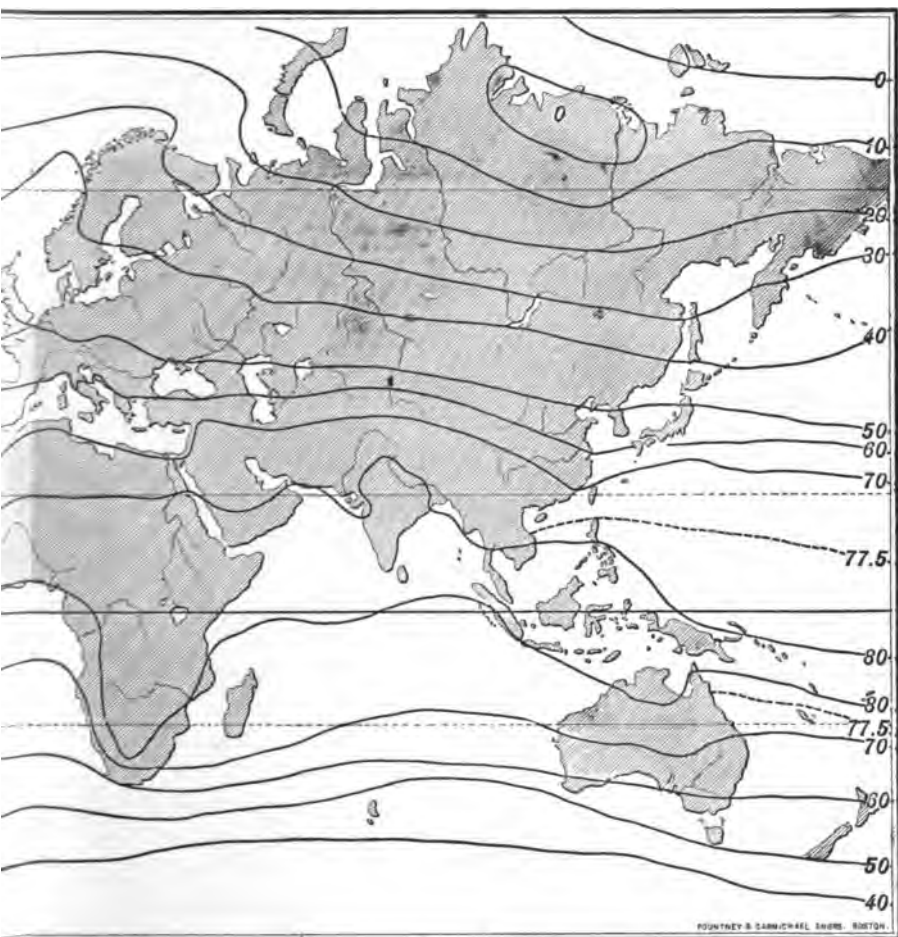


PLATE 2.
chart for the year.

replaced by a temporary descent (Fig. 25). This happens in our latitude when storms or cold waves pass over us, and prevent the effect of the sun's heat from becoming apparent. Thus in winter we may have thaws, or in midsummer the heat may be tempered by several days of cool weather; but there are more irregularities during our winter than during the summer. The temperature curve shows only the average of these, its chief value being to illustrate the effect of the sun's rays as the season changes, and to show how differently this effect is manifested in various places.

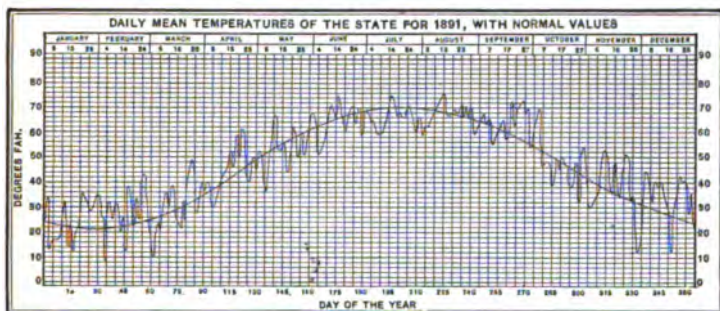


FIG. 25.

Seasonal curve for New York state. Irregular variations shown by the lighter line.

Isothermal Charts.—The best graphic way to show the distribution of temperature over the earth, is by means of isothermal charts. The *isotherm* is the line of equal temperature; and the chart may show these lines for the day, or for the month, or for the year. If for the year, they represent the *average* of *all* the temperatures during that time; or if for the month, the same average for day and night throughout the month. Every place which has the same average temperature for the period represented on the chart, has the same isothermal line. That is, if the

average temperature for a given month is 50° at London, Boston, Buffalo, etc., the 50° isotherm for that month is made to pass through each of these places.

On the isothermal chart which shows the average tem-

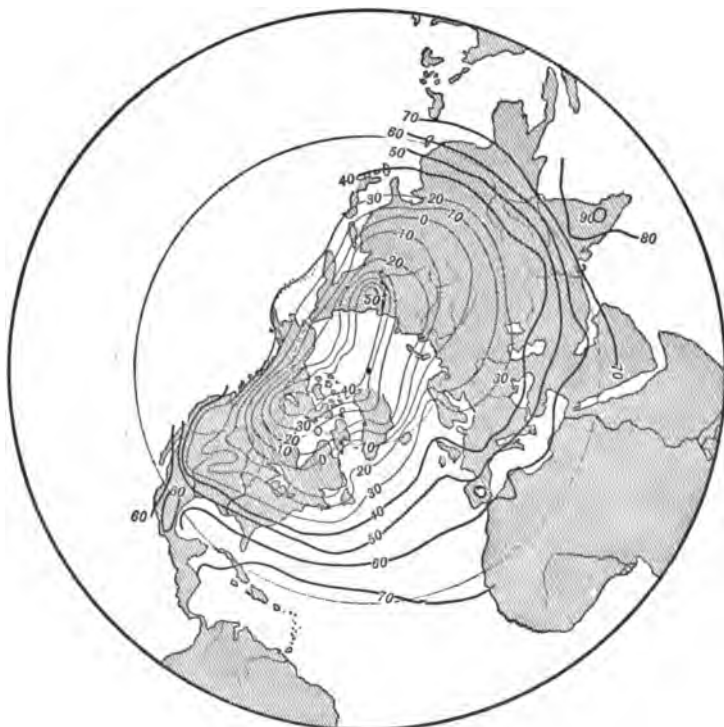


FIG. 26.

Isotherms for February, 1878-1887.

perature for the year (Plate 2), it will be noticed that in general the temperature decreases from the equator toward each of the poles; but in each hemisphere there are numerous exceptions (Fig. 26). The rate of decrease is very

variable in different latitudes. While there is a general tendency for the lines of equal temperature to run parallel with the lines of latitude, at times the divergence is so great that the isotherms extend in a north and south direction. There is much less irregularity in this respect in the southern than in the northern hemisphere; and this is easily explained by the fact that the land is mostly in the northern hemisphere. One is able to see the disturbing influence of the land in many places.

Another effect of the greater abundance of land in the northern hemisphere, is that the line of greatest heat, or the *heat equator*, is north of the true *geographic equator*. The land becomes much warmer than the ocean, and hence the highest temperatures are found in the interior of continents. This is not because more energy is received, but because the amount that does come is much more effective in warming the land and the air. Since radiation proceeds more readily from the land than the water, the average temperatures in northern regions are lower than in the southern hemisphere. Other general influences are noticeable upon the chart of annual isotherms. For instance, in the northern Atlantic, where the warm Gulf Stream extends toward the Arctic circle, the isotherms are bent northward; and along the eastern coast of the United States, where the cold Labrador current flows close to the continent, and isothermal lines are bent southward.

On the western side of North America, the influence of the prevailing winds is well shown where they blow from the warm Pacific upon the coast. This is particularly well illustrated on the isothermal charts of the United States (Plate 3), where we see a very marked difference in the temperature of the east and west coast. Thus there is a great range in temperature between Key West, on the

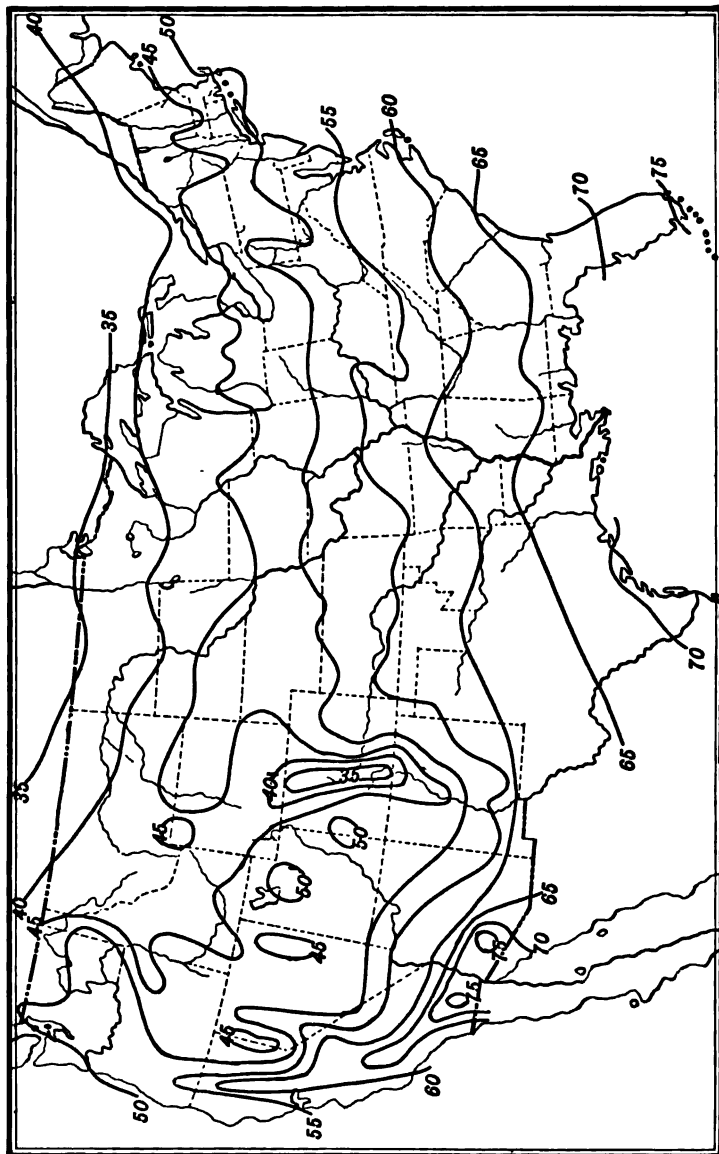
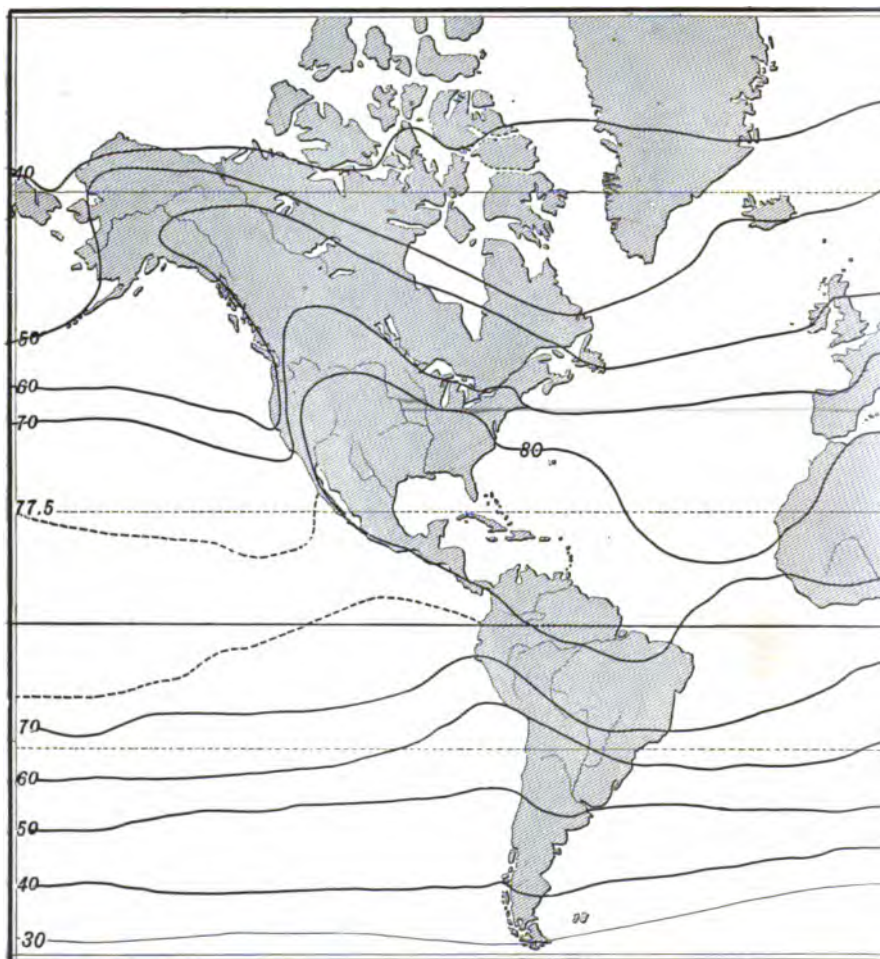


PLATE 3.
Mean annual temperature of the United States for 1892.





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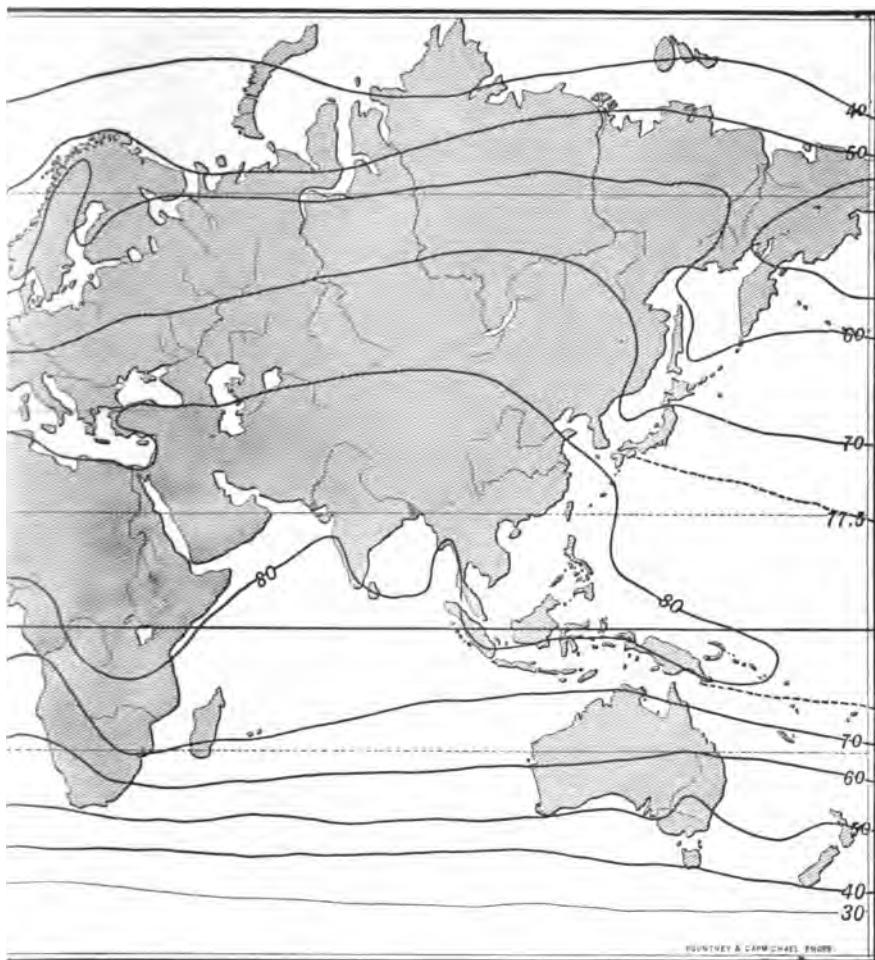
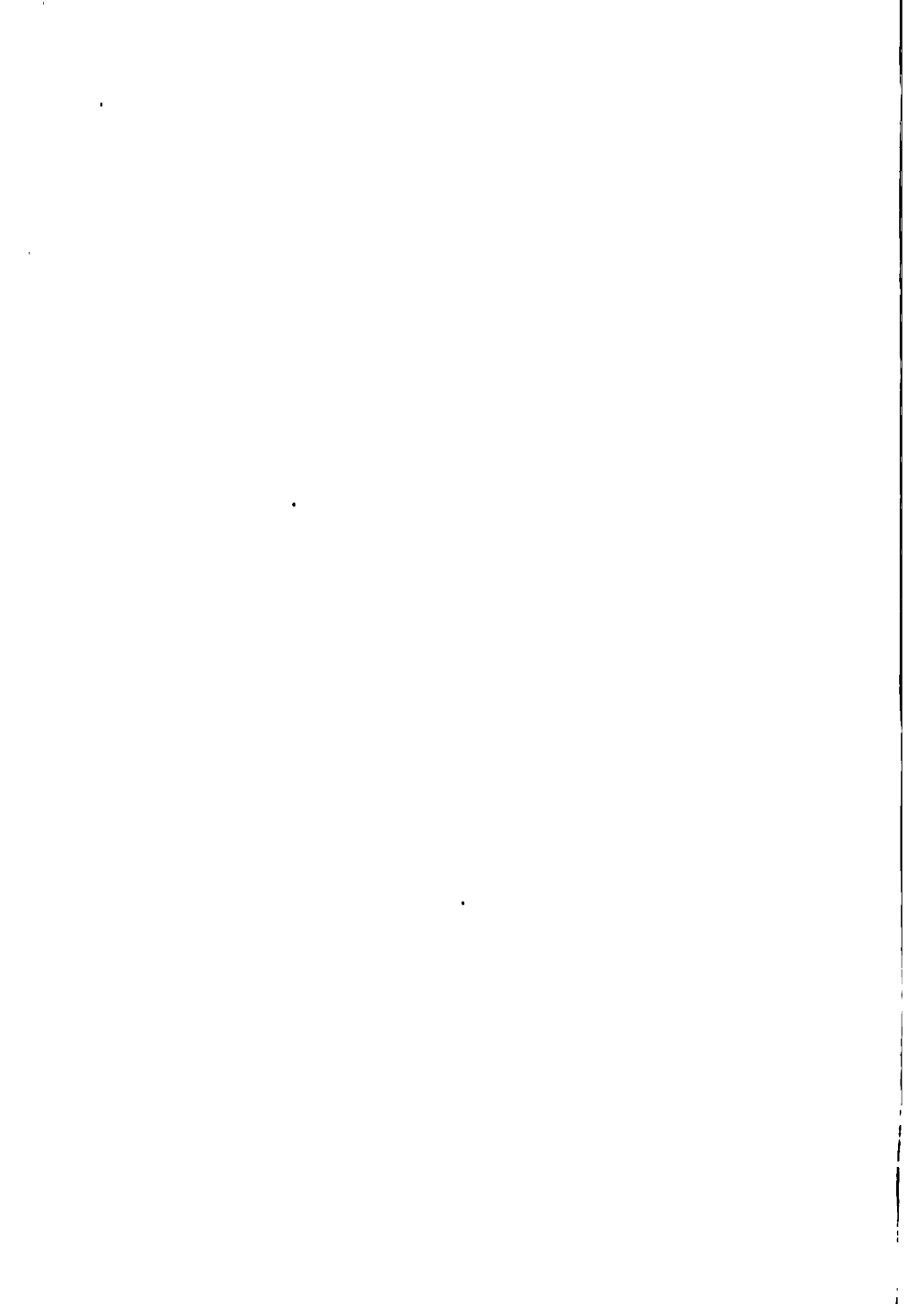


Fig. 4.
Isotherms for July.



extreme southern end of Florida, and the northern part of the coast of Maine, while in the same distance on the west coast the temperature differences are much less. From Key West to Cape Hatteras the influence of the warm Gulf Stream is felt, while on the New England coast the temperatures are lowered by the cold Labrador current; but on the Pacific coast the influence of the warm ocean is manifest from Southern California to Washington. A study of the charts will show many other variations in the isotherms.

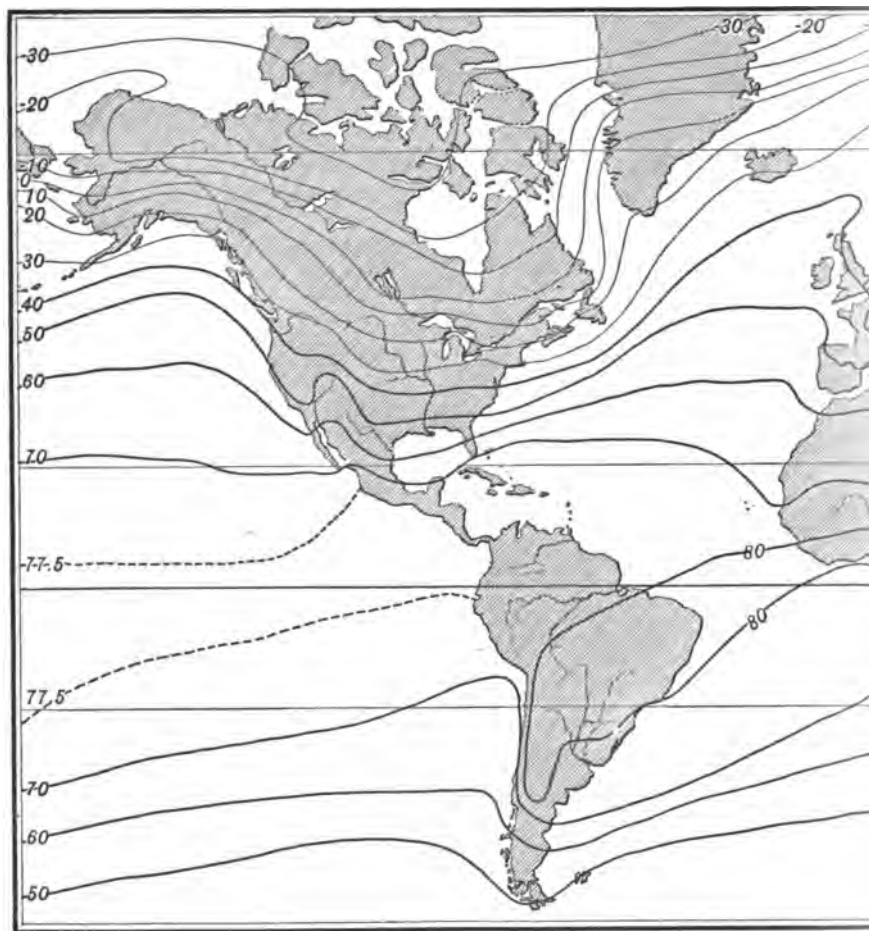
In the isothermal charts which represent the typical summer and winter conditions, similar phenomena are noticed; and in some cases they are more strikingly illustrated than on the annual chart. The heat equator of July (Plate 4) follows the sun well up toward the tropic of Cancer, but it does not follow the sun as far when it takes its southern journey during our winter; and in the Atlantic, where there is much more neighboring land, the migration of the heat equator is more marked than in the broad Pacific. We notice also that the influence of the Gulf Stream in deflecting the isotherms is more important in January than in July, when the neighboring ocean waters are themselves warmed by the summer sun.

In the two hemispheres there is also a difference in the amount of migration of the isotherms for the lower temperatures. In the southern hemisphere the isotherm of 50° in July barely reaches Africa and Australia, and its position in January is not greatly different (Plate 5). This shows the influence of the prevailing condition of water in that hemisphere; and the same fact explains the general parallelism of this isotherm with the lines of latitude; but in the northern hemisphere, where there is more land, the isotherm of freezing in July is in the Arctic

circle, while in January it extends below the 40th parallel in several places. The isotherm of 50° migrates from northern Scandinavia, Iceland, and Labrador, in July, to Spain and the Carolinas in January.

In the higher latitudes of the northern hemisphere, the influence of the land is shown by the fact that in January excessively low temperatures occur in the interior of continents. Thus so far as we know, the coldest parts of the earth are in these continental interiors, such as Asia. The winter "*cold pole*" of the world is not found high up in the Arctic latitudes, but in central Siberia near the Arctic circle (Plate 5). This is due to the fact that in these dry land interiors, radiation causes excessive cold during the long winter night. It is possible that when the Antarctic continent or the interior of Greenland are better known, we may find upon these snow-covered lands even lower winter temperatures than those of northern central Asia.

On the January and July charts of the United States (Plates 6 and 7), we find the greatest difference in temperature in the dry interior regions of Dakota and Montana, and the least at Key West and on the southern coast of California, where the equable ocean waters prevent either excessively high summer temperatures, or excessive cold in the winter. Another place where the temperature of the United States is subjected to a great range in the different seasons, is in the desert region of the Great Basin. Here the sun's rays of the summer day readily pass through the dry, cool air and raise the temperature of the ground, and the lower air layers, to a very high degree. At night and in the winter, radiation proceeds with rapidity, because the air is clear and offers little obstruction to the passage of the radiant heat; and therefore in the winter nights the temperature becomes very low.



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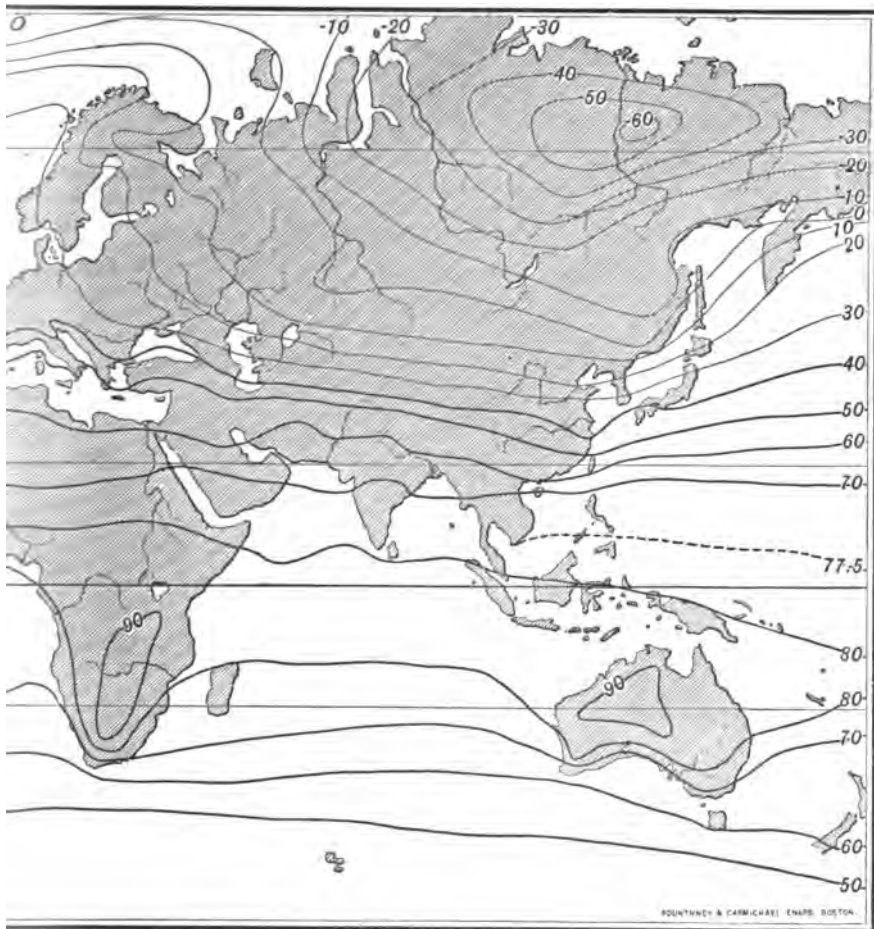


FIG. 5.
Isotherms for January.

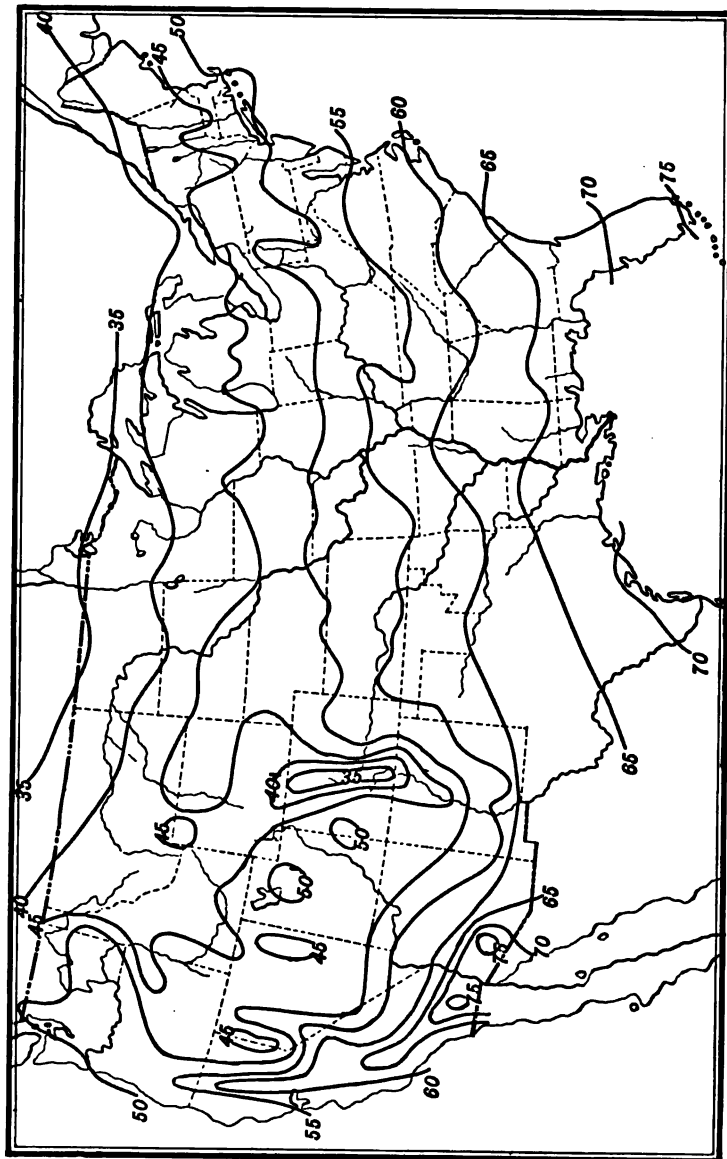


PLATE 3.
Mean annual temperature of the United States for 1892.



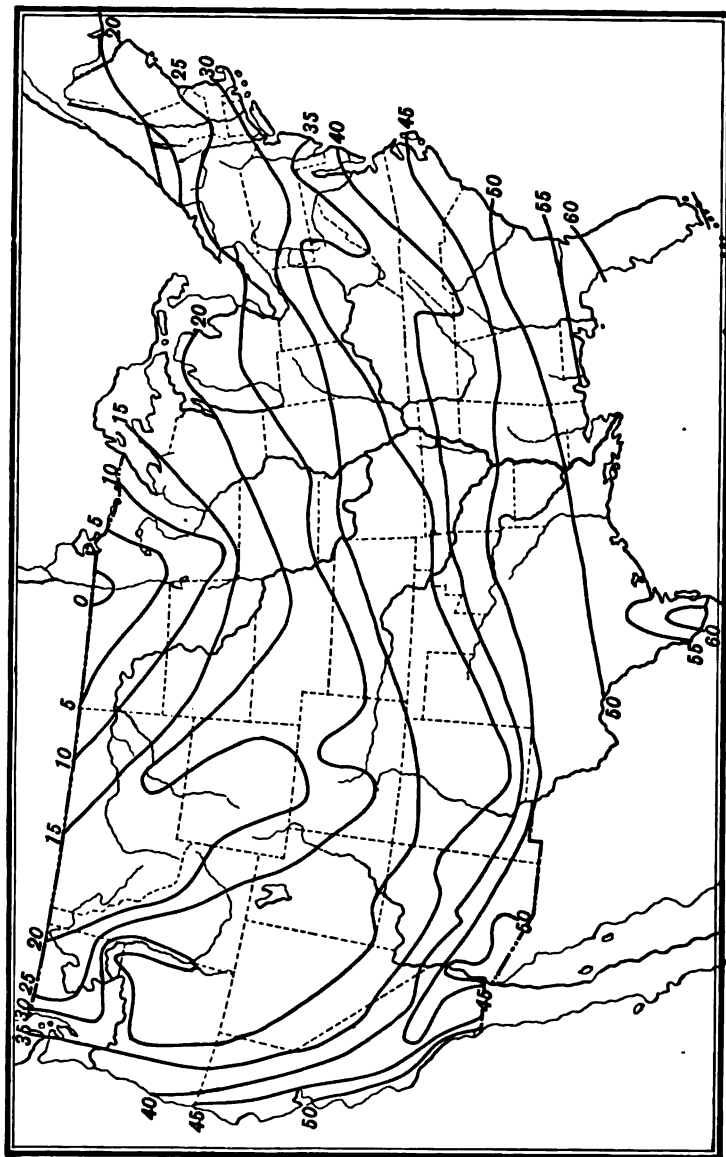


PLATE 7.

Isothermal chart of the United States for January.

The influence of topography is also well shown in several portions of the charts for the United States, and also on the New

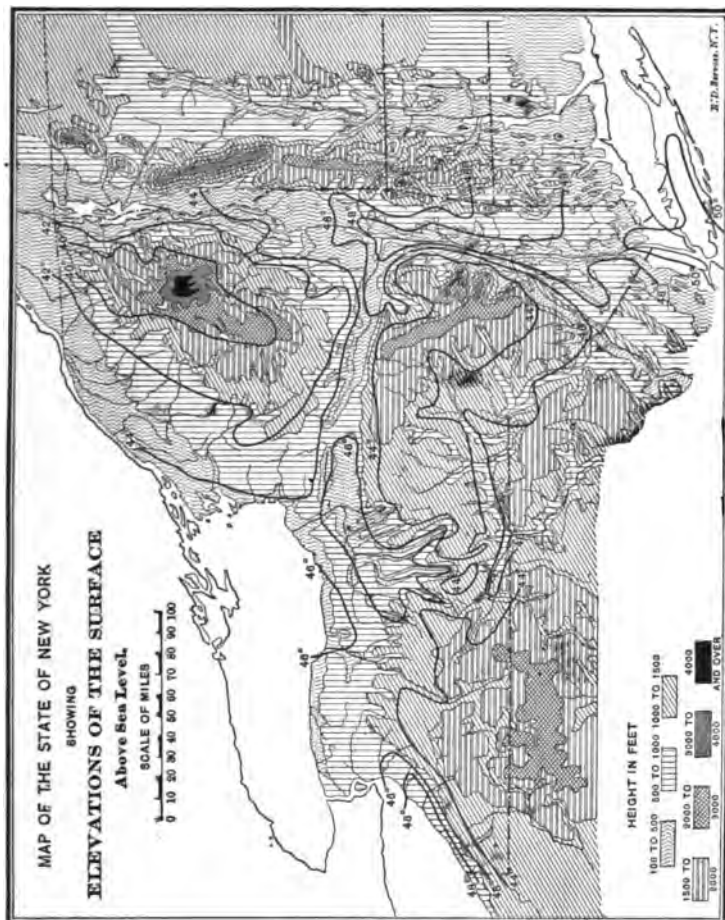


PLATE 8.

Isothermal chart of New York (average for the year).

York chart (Plate 8), where the isotherms are seen to extend up the valleys, showing that they are warmer than the hills.

Daily Temperature Curve. — The daily curve represents for the day what the seasonal curve does for the year. It shows the rise in temperature during the daytime and its fall at night (Fig. 27). Unless interfered with by some accidental cause, the temperature rises from sunrise till early afternoon, and then descends until late in the night.

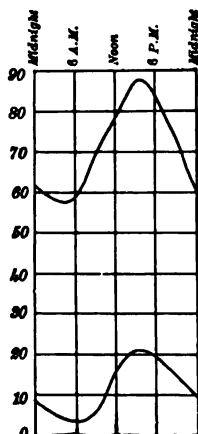


FIG. 27.

A normal daily range for summer and for winter in New York.

As in the case of the seasonal curve, the time of highest temperature is not when the sun's rays are strongest, nor is the coldest part of night at midnight. The explanation is the same, the heat of the sun in the morning being partly expended in warming the earth which was cooled in the preceding night; and the temperature at night time continues to descend after midnight, because the radiation of the heat that came during the day proceeds uninterrupted, and its influence is not checked until the sun again rises.

There is much variation in the daily curve in different latitudes (Fig. 22), and even in different places in the same latitude. The daily change in temperature is relatively slight on the seashore, and very great on the land; and the range is much greater in temperate latitudes than in the tropics. In the Arctic regions, where the sun is above the horizon in the summer and below it in the winter, the daily curve is of very little importance, and may be entirely masked by accidental causes.

Since in many parts of the earth there is a great variation in the length of day and night during the different seasons, the daily temperature curve varies with the season. Thus

in our latitude the temperature rises much higher in summer than in winter (Fig. 27).

While normally the temperature curve is that which has just been described, in reality it is subjected to many variations and interruptions (Fig. 28). The tendency is for the tem-

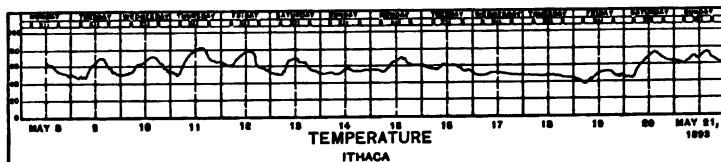


FIG. 28.

Normal daily curve followed by an interruption of several days.

perature of the day to rise above the average for that season, and to fall below it at night (Fig. 23). Oftentimes the daily curve is so changed (Fig. 29) that instead of a rise during the daytime, we have a fall in the temperature (Fig. 64); or the temperature may continue to rise through-

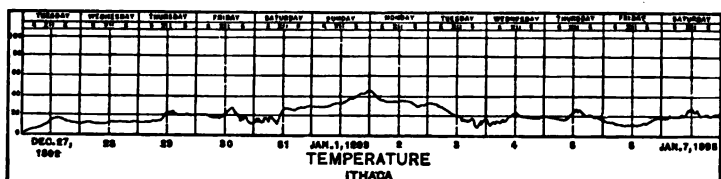


FIG. 29.

Daily temperature record, showing interference with the normal rise and fall of temperature.

out the night, the opposite of what would normally be the case. Cold waves or storms are often the causes for these changes, and many local and temporary effects may thus be produced. The presence of clouds, or of much moisture in the air, or of winds from the ocean (Fig. 39), may very

effectually modify the normal daily rise and fall of temperature.

Temperature Ranges.— The study of the isotherms of a region gives us an idea only of the *average* temperatures of different places. In a study of climate it is necessary to know something of the *changes* in temperature, both with reference to the amount (Fig. 30) and the rate.

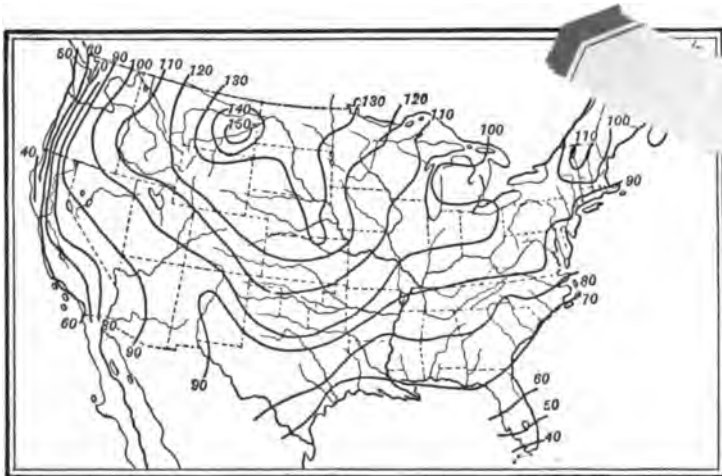


FIG. 30.

Temperature ranges in the United States in degrees Fahrenheit, 1892.

No better illustration can be found of the differences that may exist between places on the same isotherm, than that of St. Louis and San Francisco, which are on the same annual isotherm (55.7°) and on nearly the same parallel of latitude. In San Francisco, the average for September, the warmest month, is a little less than 60° , while the January isotherm is about 50° , the actual range between the averages being about 9.5° . At St. Louis, the January isotherm is 31° , while

the July isotherm is 78° , a range of about 47° . Taking the highest and lowest temperatures for each place, the difference is even more striking, for we find a range of 61° in San Francisco, while in St. Louis the range is 128° . Therefore, though they are on the same isotherm, the climates of the two places are quite different.

The lowest temperature ever accurately observed on the earth was less than -90° , the highest over 127° , the former

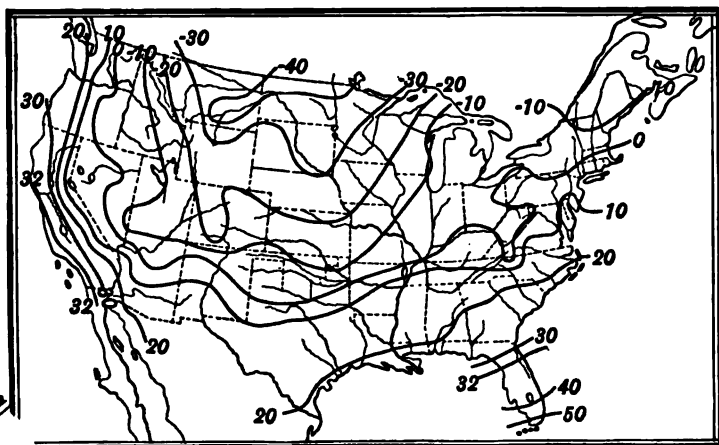


FIG. 31.

Minimum temperatures observed in the United States, 1892.

in the latter in Algeria. This is a range of nearly 216° . Extreme ranges are of course impossible in any single day, but in some of the dry interiors of continents, very extreme temperature ranges are sometimes experienced. In Siberia, where the greatest ranges are found, temperatures 181° apart have been observed; and in the northwestern states of this country, ranges of over 150° have been measured. On the other extreme, ranges of only 40° or less are

observed at Key West and on the coast of California. In some of the tropical islands of the Pacific, the greatest difference in temperature during the year is often not over 18° or 20° . More than half of our country experiences ranges greater than 100° (Figs. 30-32).

If these temperature changes came slowly, their effect would not be so very difficult to endure; but in places of great annual change, there is almost always great change

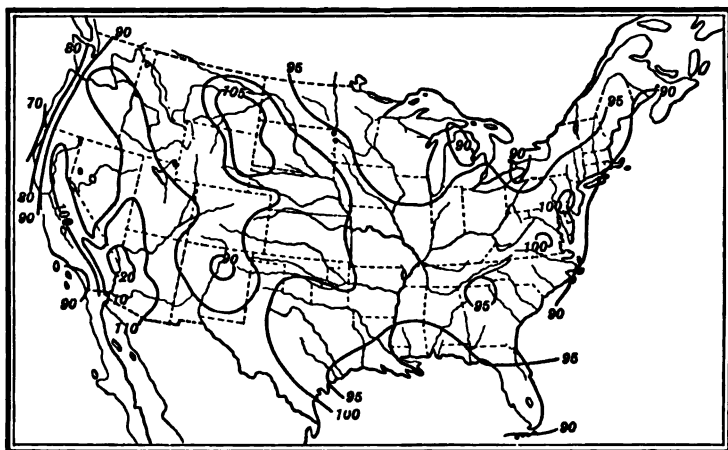


FIG. 32.

Maximum temperatures observed in the United States, 1892.

in short periods. In Montana (in December, 1880) in less than eighteen days, the temperature fell 117° , the thermometer on the 12th registering 58° , and on the 29th -59° . In the greater part of northern United States we are accustomed to similar changes in winter, though they are very rarely so extreme as this. After a few days of moderate warmth during the unseasonable winter thaws, a cold wave spreads over the eastern states, and zero weather prevails, not un-

commonly causing a drop in temperature of 60° or 70° in a few days.

We are even liable to very excessive changes in a single day. Where the air is dry, as in parts of the arid regions, a change of 40° is not uncommon in the summer, as the result of the heat of the day, followed by the coolness of the night, which is caused by the radiation through the clear dry air. Near the ocean the difference of the day and night temperature is often very slight, particularly in the winter. At Key West the day and night temperatures differed only about 7° in December, 1877.

Aside from these regular daily ranges there often occur exceptional changes (Fig. 64). In winter a cold wind may follow a rain storm and cause the temperature to descend below zero with a change of 35° or 40° in a few hours. In this case the nocturnal radiation is an aid in the fall of temperature. A daily change of 50° is not uncommon in Montana; and in Texas the thermometer has been known to fall 63° in sixteen hours. It is said that in Thibet the temperature has fallen 90° in fifteen hours, or from 68° in midday to -22° at night. In summer there are also great ranges; but they are not so noticeable, nor are they so severe, as those which come at times in winter.

Earth Temperatures.—At the very surface of the earth the ground is warmed when the sun's rays are present, and cooled when their effect is absent. Below a depth of a few feet the influence of the sun is not very noticeable, and from this point downward, the temperature of the earth is practically permanent, and is determined by the heat of the interior.

There is much difference in the effect of changes in temperature in different parts of the earth. At the equator the ground is very warm at the surface, and there is a slight variation throughout the year. At the depth of five or six feet

the intensity of the heat has decidedly decreased, and soon the zone of no variation is reached. In temperate latitudes, the difference between summer and winter temperatures is so great that the surface becomes warm in summer, and in winter cools down to temperatures lower than the freezing-point. In the winter, in such regions, frost exists in the ground often to a depth as great as six or eight feet. In the Arctic regions, where the sun's rays are of little power, and where radiation is excessive, the ground is often permanently frozen to a depth of several hundred feet. During the summer the surface layers lose their frost and thaw,

and plants grow over earth which is permanently frozen.

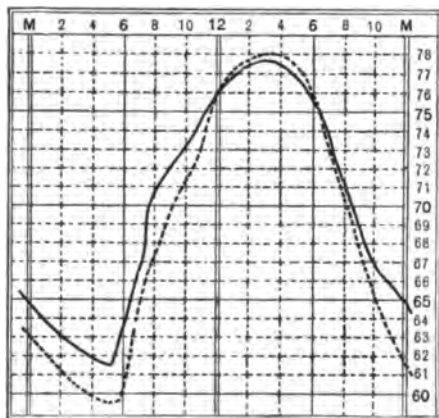


FIG. 33.

Daily range at the surface of the earth (dotted line) and of the air ten feet above (heavy line). Ithaca, N. Y., July, 1893.

The ground is such a poor conductor of heat that it takes many weeks for the effect of the summer heat, or the winter cold, to reach to a depth of ten or fifteen feet. Therefore at such depths the seasonal curve lags behind that of the air; and at the same time the temperature range is less.

At the very surface, the earth temperature changes more than that of the air (Fig. 33). This is because the earth readily absorbs heat and radiates it with almost equal rapidity. For this reason the ground at midday is warmer than the air,

while at night time its temperature is lower than that of the air. These facts of earth temperatures are important in explaining the heating or the cooling of the lower air layers.

REFERENCE BOOKS.

See also Buchan's memoir referred to at the end of the next chapter; and also the books on general meteorology, notably those by Davis, Scott, Waldo, Greely, Abercromby, Blanford, Woelkef, Hann, and Croll.

The Berghaus Atlas, volume on Meteorology (Hann, Atlas der Meteorologie. Justus Perthes, Gotha, Germany, 1887. 15 marks¹), although in German, contains many charts upon temperature distribution, etc., which will prove of value in the schools.

The Annual Reports of the Signal Service, and now of the Weather Bureau of Washington, contain much information relating to the temperature, wind, rain, etc., of the country.²

Hazen.—THE CLIMATE OF CHICAGO. Bulletin X, U. S. Weather Bureau, Washington, 1893. (Describes some interesting effects of the lake upon temperature. The other bulletins of this series are also of value.)

¹ Under the present law governing the importation of foreign books no duty is charged on those in other languages than the English. Foreign books may be ordered direct from the publishers, or through some New York, or other importers. With all charges added, the mark becomes equal to about \$0.25, the franc to about \$0.31, and the shilling to about \$0.25; but in the last case a duty may also be charged. While this does not give the actual price, it furnishes a close approximation.

² Where no price is given for government publications it indicates that they are distributed free of cost; but in many cases all of the copies are exhausted, and the only way to obtain them is from the large city second-hand bookstores. Sometimes it is not possible to obtain government publications without the aid of a congressman; but this will be easily obtained by most schools.

CHAPTER IV.

GENERAL CIRCULATION OF THE ATMOSPHERE

General Statement. — Since the air is very elastic, and its condition easily changed by variations in temperature, it is readily caused to move. No better illustration can be found of the mobility of the air under these circumstances, than that which is so often noticed on heated deserts. The ground becomes warmed, the air is heated by contact with it, and this causes the air to expand and become lighter so that a tendency to rise by convection is produced. Soon this tendency becomes so strong that the lower air must move upward, thus starting a dust whirl on the desert. The movement thus started by the effort of the denser air to take the place of the warmed layers causes very violent, though very local, winds. In a room, a warm stove, lamp, or an open-grate fire, causes the air to move, and starts a circulation which is often very noticeable.

The reverse process of cooling the lower air layers causes a condensation which necessitates a settling down of other air. We may often see an illustration of this on a cold winter night when the air is quiet. If the window in a warm room is then opened, the cold, dense outside air flows in, producing a very perceptible current.

If in place of these local illustrations, we substitute large areas of the earth's surface, we find an explanation of many of the greater features of the atmospheric circulation. Over equatorial regions, the air is constantly being warmed during the day, and therefore expanded. Accompanying this ex-

pansion, there is rising caused by the greater density of the surrounding air, and so a circulation is produced which exerts its influence over a very large area. This circulation consists of four parts: (1) the inflowing surface winds, (2) the uprising currents, (3) outflowing winds at high



FIG. 34.

Ferrel's ideal diagram of the planetary circulation. Dotted arrows show upper currents of air.

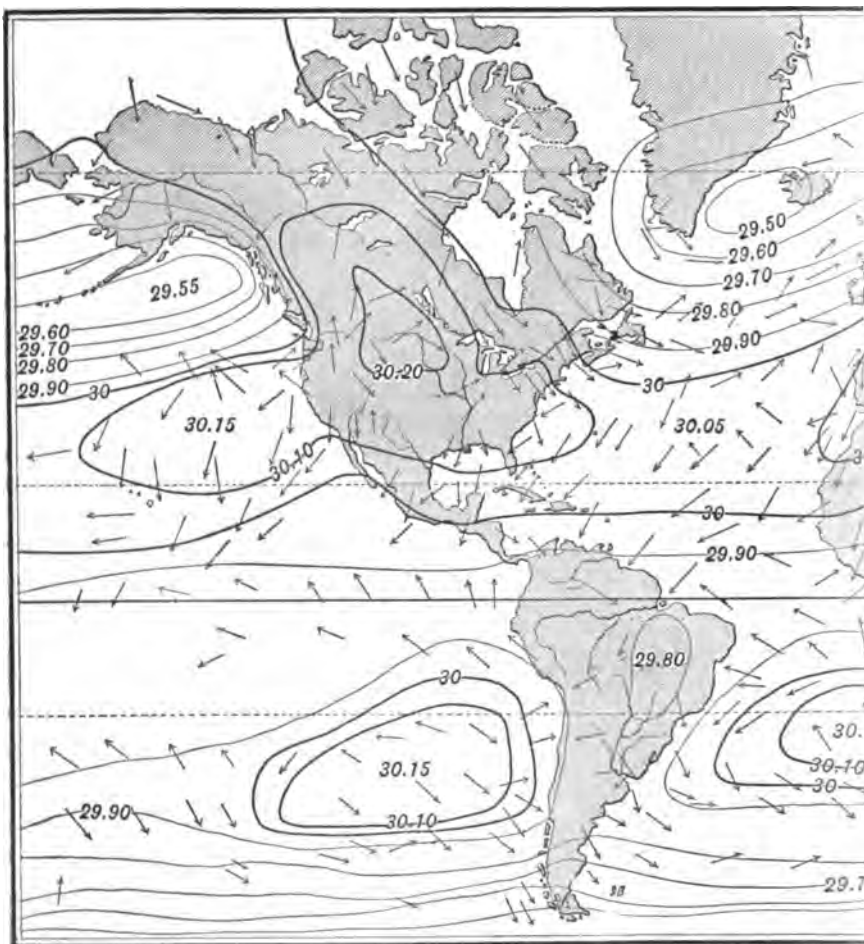
elevations, and (4) down-settling air at some distance from the equator. There are other features of this great circulation which we will soon consider. Similar winds upon a smaller scale are produced over continents, and even on the land along the seashore.

When warm air is expanded and raised it pushes away the air above it, the barometric pressure is decreased, because the air column is lighter; and when the air is cooled, it becomes

denser, and hence the barometer registers a higher pressure of the air. Therefore the relation between air pressure and wind is very intimate; and where, for any reason, low-pressure areas exist, winds are found blowing toward them (Plate 9). This is the case in certain areas which are permanently warmer than the surrounding regions, and also in those disturbances of the air which are classed as storms. A *barometric gradient* is produced, and the winds move as if they were going down grade. The air moves away from high and toward low pressure areas.

Classification of the Winds. — For the sake of simplicity in the consideration of the movements of the atmosphere, it seems well to adopt some classification of air movements. The one here proposed is a logical division; but other classifications might be used, the only object of such a division being to group like kinds.

Planetary or Permanent. (Due to planetary causes of a permanent nature.)	{	Trades.
		Anti-trades.
		Doldrums, or equatorial calms.
		Horse latitude winds and calms.
		Prevailing westerlies.
Periodical. (Due to periodical causes.)	{	Seasonal winds
		Diurnal winds
		Eclipse winds.
		Tidal breezes.
Irregular. (Due to causes apparently of an irregular nature.)	{	Migrating winds and calm belts.
		Monsoons.
		Land and sea breezes.
		Mountain and valley breezes.
	{	Desert whirlwinds.
		Cyclonic winds.
		Anticyclonic winds.
		Thunderstorm winds.
		Tornado winds.
	{	Landslip blasts.
		Avalanche blasts.
		Volcanic winds.
		Waterfall breezes.



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Winds and isobars

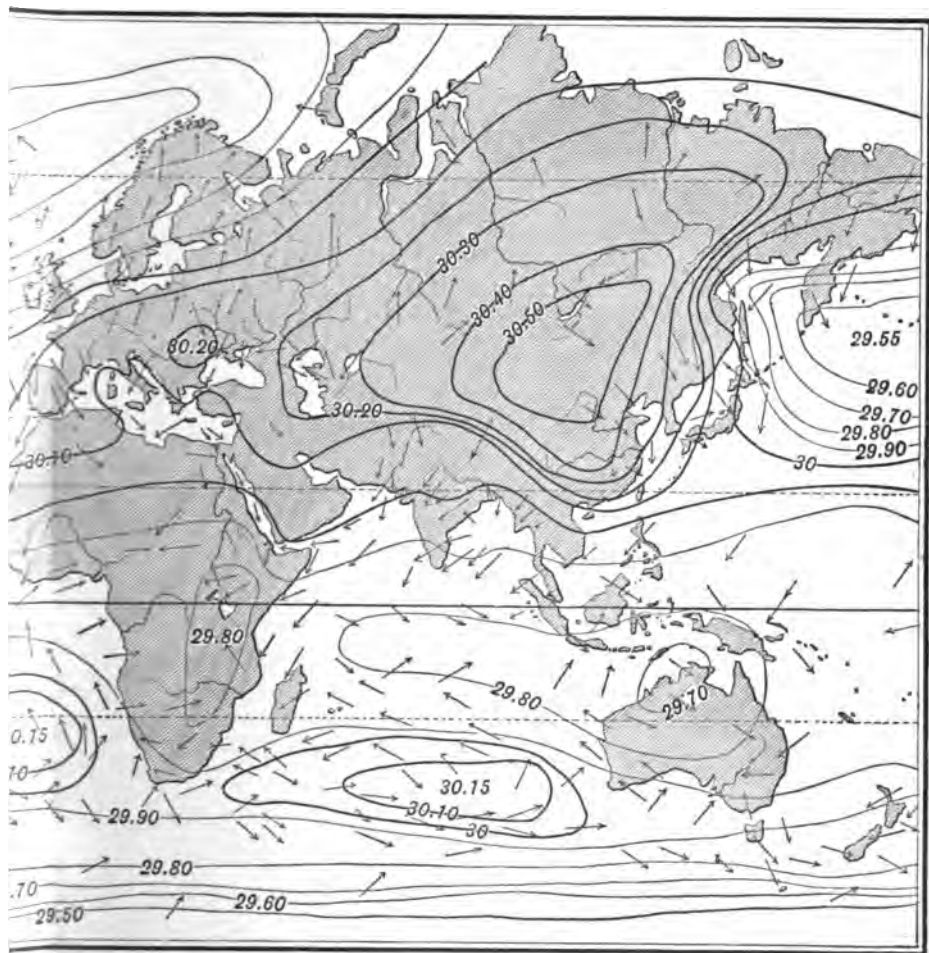


PLATE 9.
of the globe for January.

Planetary or Permanent Winds.— There are certain winds whose force and direction depend upon the fact that there is a variation in the amount of heat received in different latitudes of the earth, and that the earth is rotating about its axis. These may be called *planetary* winds, because they would be developed upon any planetary body where similar conditions prevail. Or we may call them *permanent*, because, compared with other winds, their direction and force are practically permanent. In some places they are greatly modified by other causes; but they are so strongly developed that their influence is felt all over the earth. They are, as it were, the general atmospheric winds; and together they form the fundamental circulation of the atmosphere. They may be described under several headings.

Trade Winds.— Since the air over the equatorial regions is warmed more than that on any other part of the earth's surface, the denser air moving in toward the warmer region causes currents. The equator may be fairly compared with a stove, over which air rises by convection, and toward which currents flow. These inmoving winds are called the *trades*, because they blow with marked permanency and steadiness; and in planning their journey, whenever possible, vessels choose a course which will allow them to take advantage of the trade winds. These winds move toward the equator (see Plates 9, 10, and 11), but instead of blowing directly toward it, they are deflected by the effect of the earth's rotation. North of the equator their direction is from the northeast, while south of it they move from the southeast. They are much less well developed over the land than over the water; and when they blow from the water to the land, they are often deflected because of its influence. Over the land they may even be destroyed.

The air in the trade winds is moving from colder to

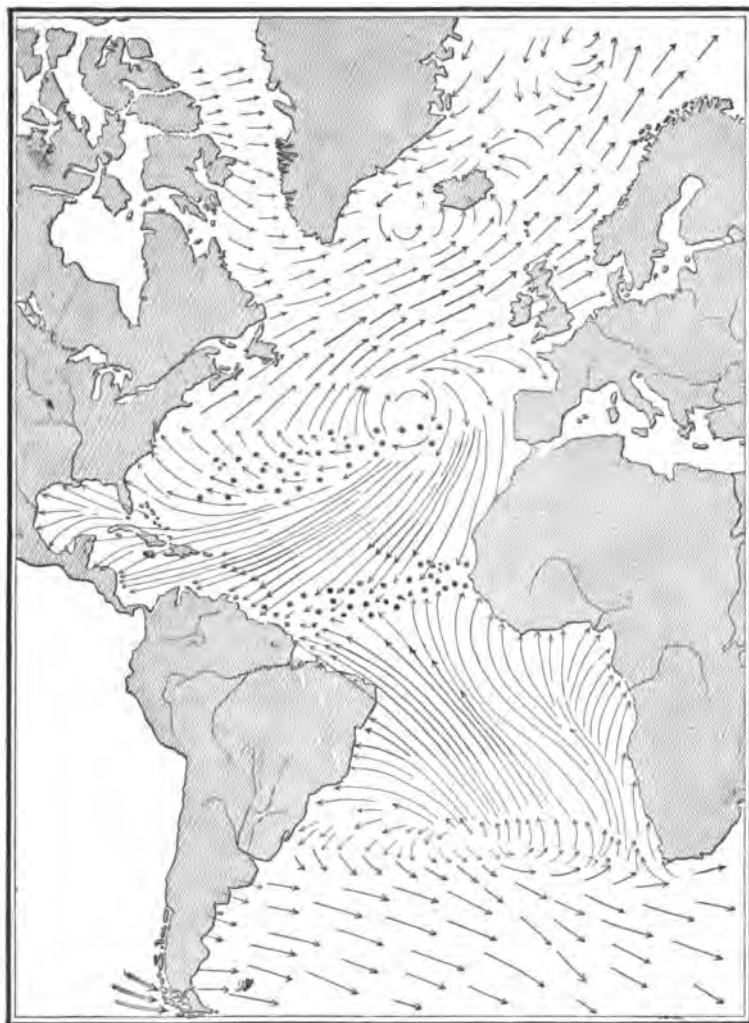


PLATE 10.

General circulation of the Atlantic for July.

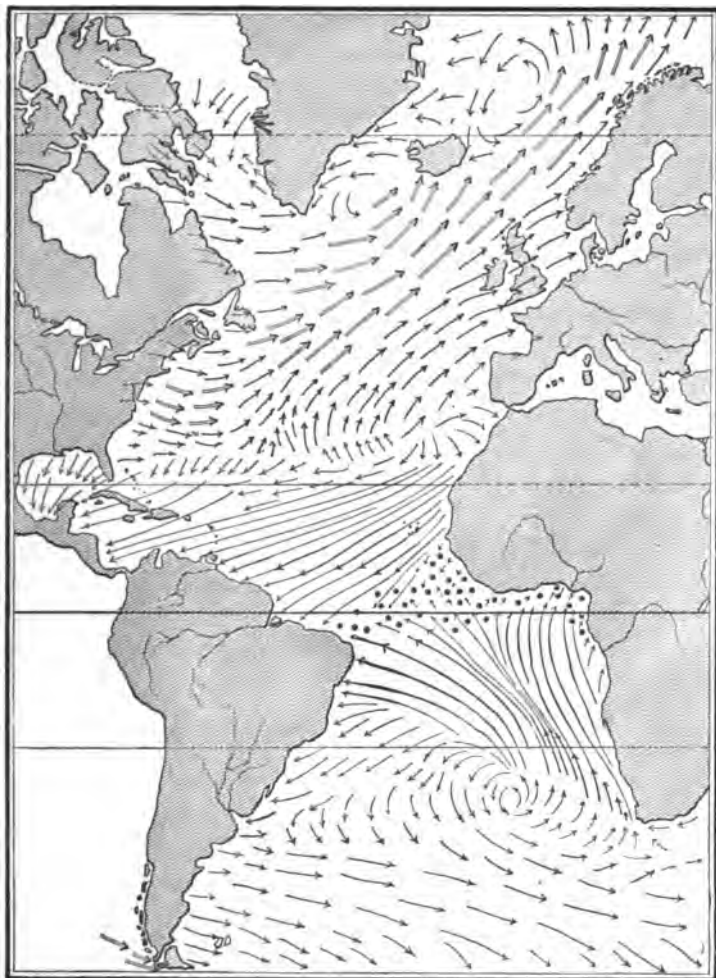


PLATE 11.
General circulation of the Atlantic for January.

warmer regions, and therefore its capacity for water vapor is constantly increasing. Therefore they are drying winds, and when they blow over the ocean, evaporation is rapid, while on the land, where water vapor is not readily obtained, they produce deserts in many places. Since the temperature of this air is high, when blowing over the ocean the amount of water vapor which it is enabled to carry is very great; and much rainfall is caused if the air is made to rise, as is the case when the trades blow upon rising coasts.

Doldrum Belt.—Over the heat equator, the air in this great planetary circulation rises by convection; and in this place a condition of almost permanent calm is produced (Plates 10 and 11). This is particularly the case over the oceans, but over the land other causes may interfere. The *doldrum belt* is situated between the north and south trade winds, and it migrates from season to season as the heat equator changes its position. Since the air in this belt is warmed, it contains much water vapor, and it is a very rainy belt because this humid air rises by convection, and cools dynamically until the dew-point is reached. Therefore, during the day the sky almost invariably becomes cloudy, and rains fall.

Anti-trade Winds.—The inflowing of surface air, and its uprising, makes necessary an outflow of air at a higher level. This outflowing air moves away from the equator, in either direction, and produces what is known as the *anti-trades*. These winds are not felt on the land, excepting on those rare peaks which rise to a height of 10,000 or 12,000 feet above sea-level. They move in a northeasterly direction in the northern hemisphere, and toward the southeast in the southern, in each case being turned from a true north or south direction by the deflective influence by the earth's rotation. Their permanency is shown by the fact that the upper clouds

move in these directions. This upper air movement continues in the temperate latitudes.

Horse Latitude Winds.—After traveling for a certain distance from the equator, the air commences to settle, and some of it reaches the earth's surface near the poleward margins of the trade wind belts. These regions of settling air are known as the *horse latitudes*, and because the air is descending in these belts, the prevailing condition is that of calms or light, variable winds; but these calm belts are not so pronounced as those of the doldrums (Plates 10 and 11). Over the land, the horse latitude belt is not so distinctly developed.

Prevailing Westerlies.—A part of the upper circulation of the anti-trades continues toward the poles; and because the polar regions are places of permanent low temperature, there is a tendency for the upper air to move toward them. These air currents are deflected to the right in the northern, and to the left in the southern hemisphere, so that in the upper latitudes there is a whirl of air known as the *circumpolar whirl*, which, in both hemispheres, produces a condition of prevailing westerly winds, both near the surface (Plates 10 and 11) and in the upper layers of the atmosphere. These whirls produce a condition of permanent low pressure in the polar regions; for there is an eddy produced, which is somewhat analogous to that formed by the escape of water from a bath tub.

In the upper air the east-moving winds are remarkably permanent, as any one may see by watching the movements of the upper clouds. At the surface, the tendency toward the development of east-moving air currents is greatly interfered with by other causes. This is much more strikingly shown in the northern than in the southern hemisphere, where land is less abundant. In the latter hemisphere, sailing vessels may go around the earth with prevailing fair winds driving them onward (Plate 9). To do this, they

must go past Cape of Good Hope, and return by way of Cape Horn. In the northern hemisphere, the most striking influence of the prevailing westerlies upon the surface, comes from the fact that they determine the path of movement of the greater number of our storms.

Periodical Winds. — There are certain changes of a periodical nature, which tend to start the air in motion in a definite way; and this tendency is repeated as these periods return. The most important of these changes are those which arise from the variation in supply of solar energy in the different seasons, and in the change from day to night. The periodical winds may therefore be classed as *seasonal* and *diurnal* winds; and in the group may also be included two minor classes of periodical winds, *eclipse* and *tidal* breezes.

Seasonal Winds. — We get a large supply of heat in one season, and a very much smaller amount in the opposite season; and the differences in seasons are very much greater far from the equator than they are in the equatorial belt. Therefore the seasonal effect upon the atmosphere, is less marked in the equatorial belt than elsewhere on the earth's surface. Still, even in equatorial regions, as the season changes, the movement of the sun in the heavens produces a very decided effect upon the atmospheric circulation.

Migrating Wind and Calm Belts. — The wind charts of the Atlantic Ocean (Plates 10 and 11) show that there is a migration of the belt of calms as the season changes. The trade wind belts also move northward and southward; and therefore in one season a region within the tropics may experience the calms of the doldrums, while in the opposite season, the dry and permanent trade winds blow steadily day after day. In the same way, a region situated near the northward or southward margin of the trade wind belts, may in one season feel the trade winds, while

in the opposite season the variable winds of the horse latitudes prevail.

Monsoon Winds.—In latitudes outside of the tropics, where large land masses exist, very interesting winds are often caused by the difference in temperature between the land and water. During the summer the land areas become warmed, and are covered by an area of permanent low pressure, toward which air currents move from all directions (Fig. 35). The air rises over the warm land, and its place is taken by air from the relatively cool oceans. In the winter season, the land becomes cooler

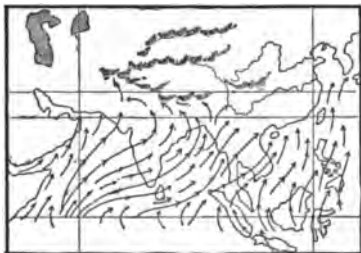


FIG. 35.

Summer monsoons in India.

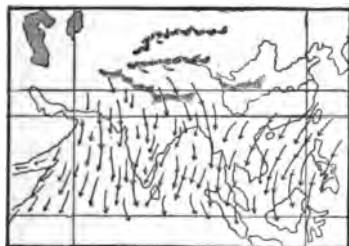


FIG. 36.

Winter monsoons in India.

than the water, and the air is caused to settle over the land and to move out from these areas of high pressure (Fig. 36), toward the then relatively warm oceans (Plate 9). This class of wind, which is very pronounced in Asia, is known as the *monsoon wind*. Similar winds are noticed in other continents, and we now know this class of air movements as the monsoons.

In Asia, the monsoon winds blow in toward the central regions, across India, China, and other countries. During the winter they blow in the opposite direction. In Australia and other continents, the monsoon system of winds is very well developed; and on the Spanish peninsula, the same

tendency toward inflowing summer and outflowing winter winds is quite pronounced.

Even where the distinct monsoon condition is not produced, a tendency to the production of this class of wind often expresses itself in the disturbance of the wind direction. This is very well illustrated along the Texas coast, where the summer trade winds are deflected until they blow upon the land. This phenomenon is shown on Plates



FIG. 37.
The sea breeze.

10 and 11; and on these charts it will also be noticed that in the winter, the prevailing winds of the coast of northern United States are from the land toward the ocean, while in summer their direction is much less definite. That is to say, the prevailing westerly winds are strengthened in winter and weakened in summer by the monsoon tendency, which in summer is not sufficiently powerful to entirely invert the prevailing westerlies.

In cold regions, such as Greenland, there is a tendency toward the production of outflowing winds in summer, because the snow-covered land is colder than the water. Another continental effect, not, however, dependent upon the temperature differences, is the retardation of winds in their passage over the land. As a result of friction, the winds of the land are less violent than those of the water; and mountain ranges may effectually check the winds and destroy them.

Diurnal Winds: Sea and Land Breezes. — Since the heat of the day is followed by the coolness of the night, the atmosphere is often caused to move locally. During the summer this is particularly well shown along the seashore, when the familiar sea and land breezes are often produced on calm days and nights. During the day the land becomes warm and air tends to flow toward the warm areas from the cool sea, thus producing a very refreshing sea breeze (Fig. 37). This breeze begins to blow late in the morning, and continues until the power of the sun has decidedly diminished. It does not come every day, but only when other atmospheric disturbances are not markedly developed. It causes a peculiar disturbance of the normal daily temperature curve. In ordinary cases the highest temperature of the day comes in the mid-afternoon; but when the sea breeze commences to blow, the temperature usually falls, so that the highest point reached during the day may be before noon (Fig. 39). The sea breeze does not generally extend far inland; and ordinarily at a distance of ten miles from the coast, it is hardly perceptible.

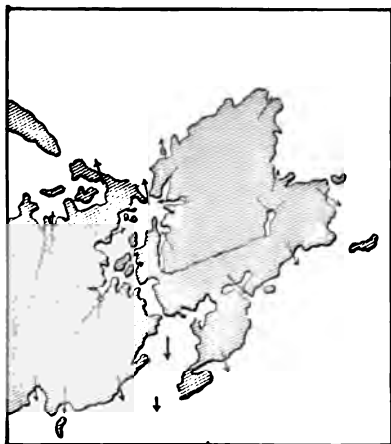


FIG. 38.
The land breeze.

At night, when the land has become cooler than the ocean, a very gentle breeze often blows out upon the water (Fig. 38), rarely more than a few miles from the shore. This is the land breeze; and thus it will be seen that by the daily

change in temperature there is produced a local circulation resembling in a small way the more extensive continental or monsoon circulation which depends upon seasonal changes in temperature.

Where prevailing winds blow upon the coast, as is often the case in the trade wind belt, the intensity of these winds is sometimes considerably increased during the day, by the

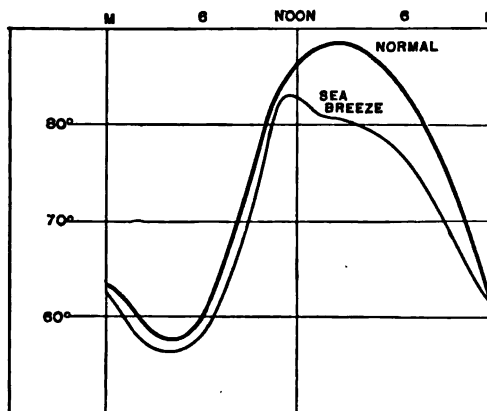


FIG. 38.

Diagram showing normal daily curve on a hot summer day, and the effect produced by the sea breeze.

air to rise, and freshens the winds by increasing their strength. Thus during a day which is calm in the morning, strong winds may arise, and die down as the sun sets.

Along the shores of large lakes, a lake breeze analogous to the sea breeze may arise during hot summer days. This is particularly noticeable along the shores of the Great Lakes of North America, and it is one of the reasons for the strong winds which prevail in such lake shore cities as Chicago.

Mountain and Valley Breezes.—Where the topography of a country is very irregular, as in mountainous regions, the

combination of the sea breeze and the normal wind. Even on the land, where no tendency to the production of the sea breeze is present, the change in temperature between day and night produces an effect upon the winds.

The heat of the daytime causes the

change in temperature between day and night often produces a set of winds known as the mountain and valley breezes. During the nighttime, the air near the surface becomes cool by radiation, and it therefore becomes more dense and contracts. This dense air slides down the mountain sides into the valleys, down which it flows, often with sufficient velocity to cause gales.

Just as streams gather water, and thus constantly increase their velocity by additions from their upper branching tributaries, so these down-moving air currents become concentrated near the outlets of the mountain valleys. Among the valleys in the Rocky Mountains, during the calm clear days of summer, when no other influences are

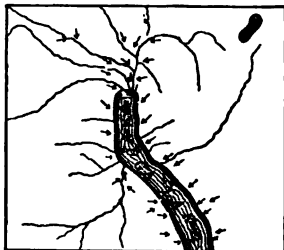


FIG. 40.
Mountain breeze.

present to disturb the tendency, these mountain breezes, or we might say mountain gales, are of nightly occurrence.

The heating of the mountain sides during the day causes an updraft of air, which is the valley breeze. This is much less intense than the mountain wind, partly because the air is obliged to ascend against the action of gravity, and partly because the upflowing air is not concentrated during its ascent, but is rather disseminated over the mountain and valley sides. The day breeze becomes most intense in the mid-afternoon; and the night breeze attains its maximum development just before sunrise.

This type of wind is by no means confined to mountains, but is very well developed in plateau regions, such for instance as that of central New York, near Ithaca (Fig. 40). This plateau is dissected by numerous deep valleys which converge toward the broad depression occupied by Lake

Cayuga. At nighttime the air flows down these valleys, producing perceptible breezes. Concentrated in the larger valley occupied by the lake, the wind often develops into a strong breeze during the calm summer nights; and the wind lasts until eight or nine o'clock in the morning. No breeze of the valley type has been noticed here. It is probable that in the other similar valleys of this region the same breeze is produced; and it may be expected in almost any place where the land is deeply cut by valleys.

Eclipse and Tidal Breezes.—These are practically unimportant. During total eclipses of the sun, breezes have been noticed whose origin seems to be due to this unusual interference with the sun's rays. Where tides rise to a great height, as for instance in the Bay of Fundy, local observers report that an increase in the wind accompanies the rising tide. Little is known about this type of tidal breeze, and it is possible that the breeze is due to other causes.

Irregular Winds.—These winds are irregular in direction and intensity, and they depend upon causes which do not return with regularity. In these respects they are quite distinct from the permanent planetary winds, and from the regularly recurring seasonal and daily winds. They therefore deserve to be grouped in a separate class. *Storm winds*, the most important of this group, are considered in Chapter V. Their important influence in disturbing the planetary circulation is well shown on Plates 9, 10, and 11.

Accidental Winds.—These winds are rare, and depend upon some accidental cause which starts the air in motion. Perhaps the most common wind of this class is the *landslip* or *avalanche blast*. In mountains, and more rarely in other places, large masses of earth and rock are sometimes precipitated for a considerable distance down some steep slope. These landslides, or avalanches, displace a considerable mass

of air, and form exceedingly violent local winds, which at a distance of a few hundred yards have in some cases been known to overturn trees and houses.

During volcanic eruptions of a violent nature, vast quantities of air are started in motion; but the effect of these *volcanic winds* is not usually important upon the surface, because the displaced air is high above the ground. The *waterfall breeze* is a gentle breath of air extending out from the base of a waterfall.

The Nature of Winds.—The wind is a bodily movement of the air, but it is not necessarily a steady movement. Every one has noticed that the wind blows in gusts, and that now it is strong, and again very light. In some respects these pulsations are like waves; and it has lately been found that even when the wind appears to be blowing steadily, it is really made up of a large number of gusts or pulsations, which can be detected only by very delicate instruments. Even during strong winds there may be momentary calms.

Nor are the winds a perfectly horizontal movement of the air. As the air moves over an irregular country, it is in some cases deflected upward, and in other cases downward. Another reason for the introduction of a vertical element into wind movements, is the fact that upper air is sometimes settling, while in other cases, as a result of convection, the air near the surface is ascending.

These irregularities in air movement make the wind an exceedingly complex series of motions, in which the predominating direction is horizontal, but in which also there are a number of vertical movements. It seems very probable that it is these vertical movements which birds make use of in soaring. Such birds as hawks and eagles are able to float about in the air, and even to rise apparently without

making movements with their wings. There may be an internal work of the wind which these birds have found, and made use of in their flight, sorting out those movements which they need, and not being retarded by those which are opposed to their motion. It has been suggested by Professor Langley that it is not impossible that these air movements may be employed in aerial navigation by man himself.



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Ferrel. — **A POPULAR TREATISE ON THE WINDS.** Wiley & Sons, New York. Second edition, 1890. 8vo. \$4.00. (In part a republication of Recent Advances in Meteorology, Report of U. S. Signal Service for 1885, Part II., Washington.)

Buchan. — **REPORT ON ATMOSPHERIC CIRCULATION, CHALLENGER REPORTS, PHYSICS AND CHEMISTRY, Volume II.** Eyre & Spottiswoode, London, England, 1889. 4to. 52s. 6d. (Contains a remarkable series of charts relating to temperature, pressure, and atmospheric circulation.)

See also the general books by Davis, Waldo, Greeley, and others, referred to at the end of the other chapters.

CHAPTER V.

STORMS.

Cyclonic Storms.— As used here, a storm is any condition of cloudiness accompanied by rain. On coasts that

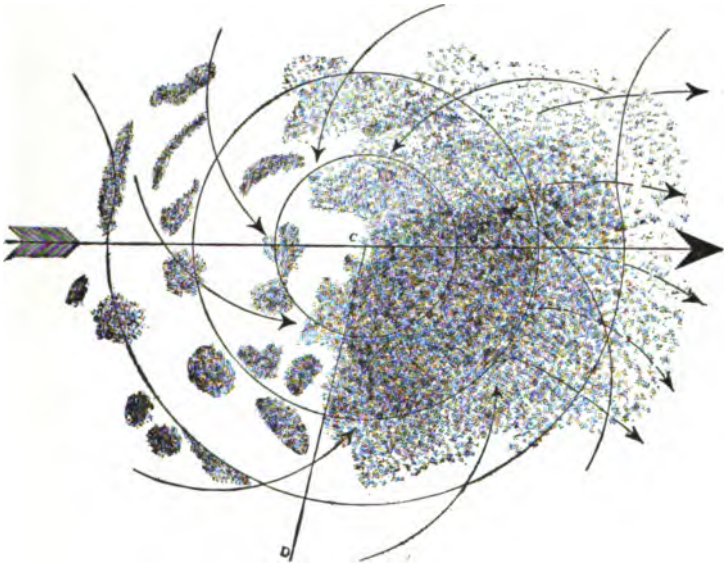


FIG. 41.

Ideal diagram of a storm. Large arrow shows path of storm; small arrows, inblowing winds; circles, lines of barometric pressure; and shaded areas, distribution and intensity of rain.

rise in the paths of moist winds, clouds and rain are often caused by the condensation of water vapor, which results

from the rising of the air, and the consequent cooling until the dew-point is reached. In the same way, air that rises as a result of convection may reach the dew-point, thus forming clouds and rain. These kinds of rainstorms are not of particular importance in northern United States, and therefore need not be considered in detail.

These causes *aid* in the formation of the very important group of storms which bring the greater part of the rain that falls in the northern half of this country. To these the name cyclonic storms may be given; and these are not of

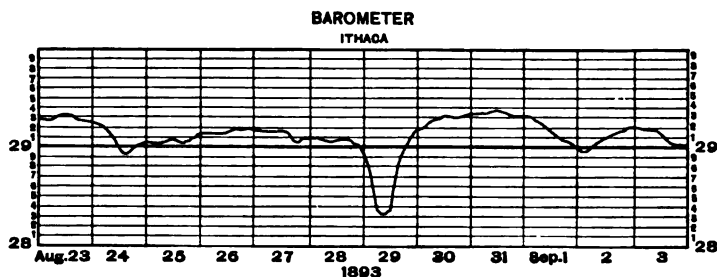


FIG. 42.

Fall of the barometer during the passage of the center of a hurricane near Ithaca, New York.

importance merely in this part of the United States, but they are developed on many portions of the earth's surface. We may divide them into two groups, the tropical cyclones, or hurricanes, and the temperate latitude cyclones.

Hurricanes. — *Description.* In the warm Atlantic tropical belt north of the equator, violent storms begin and move toward the American coast, along which they pass in their course, which is then usually northeastward across the Atlantic. These are the typical *hurricanes*; and in the North Pacific similar storms occur, which are there known as *typhoons*. Storms of this nature are also found in the

South Pacific and Indian oceans; but none occur in the South Atlantic, and none appear to originate on the land. They are typical productions of the tropics, and in these regions often attain extraordinary violence; but in our latitude, although they are the most severe storms that we experience, they have lost much of their tropical violence.

As one of these hurricanes or typhoons approaches a place, the sea is calm and glassy, and the air quiet and sultry. The pressure decreases (Fig. 42), and wind begins to blow with increasing violence, while clouds overspread the sky, at first as a thin hazy veil, which gradually changes to a solid mass of dark clouds from which rain falls. The wind increases to a gale and gradually shifts its direction, while at the same time the barometer falls. If the place of observation happens to be in the path of the center of the storm, as this is neared the wind decreases in violence and suddenly changes to a calm, while the sky overhead becomes clear. This is known as the "eye of the storm." As the storm passes onward, the wind begins as suddenly as it ceased; but this time it is from the opposite quarter, and then, in reverse order, conditions are experienced which resemble those noticed as the storm approached.

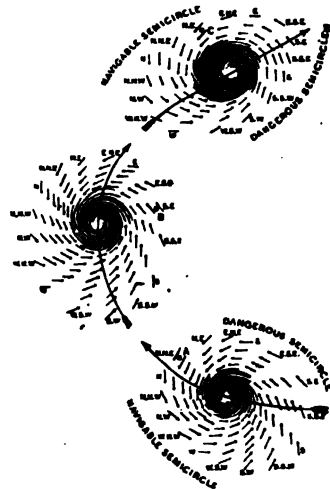


FIG. 43.

Diagram of spirally inflowing winds of the hurricane, together with the path pursued by the storm. Spiral movements greatly exaggerated.

These conditions indicate that the storm is a mass of

whirling air, toward the center of which the winds are blowing from all directions, along spiral courses, as is shown in the accompanying diagrams (Figs. 41, 43, and 44). The hurricane is therefore not unlike the desert dust whirl which was described in the last chapter. Air is moving toward a central area, where it ascends and flows away in the air

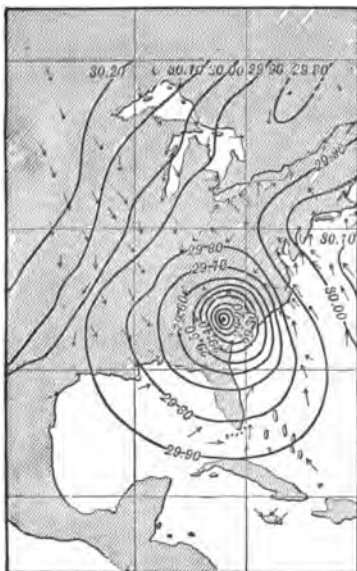


FIG. 44.

Diagram showing conditions of wind and pressure in an actual hurricane.

above. This outflowing of the air in the upper parts of the storm, is shown to exist by the movements of the upper clouds, which extend outward as long streamers.

Effects.—The violence of the winds in a hurricane is almost incredible, and many a ship that has been drawn into the dangerous whirl has not been able to escape destruction. The tendency is for a vessel to be whirled around the storm center; and if it happens to pass through the center or “eye of the storm,” the sudden change in the direction of the wind may come so quickly that the ship is not able to adjust its

course in time to prevent foundering.

When these hurricanes pass over oceanic islands, they often cause much devastation; and the destruction of several war vessels at the Samoan Islands, in 1889, was a result of one of the South Pacific hurricanes. The history of the West Indies, and of the southeast coast of Asia, is replete

with instances of the destruction of stout vessels that have been overtaken by hurricanes or typhoons.

Accompanying the storms, there are often great ocean waves which sweep over low-lying coasts, sometimes completely destroying all life and property in the areas visited. On September 15, 1875, three-fourths of Indianola, Texas,

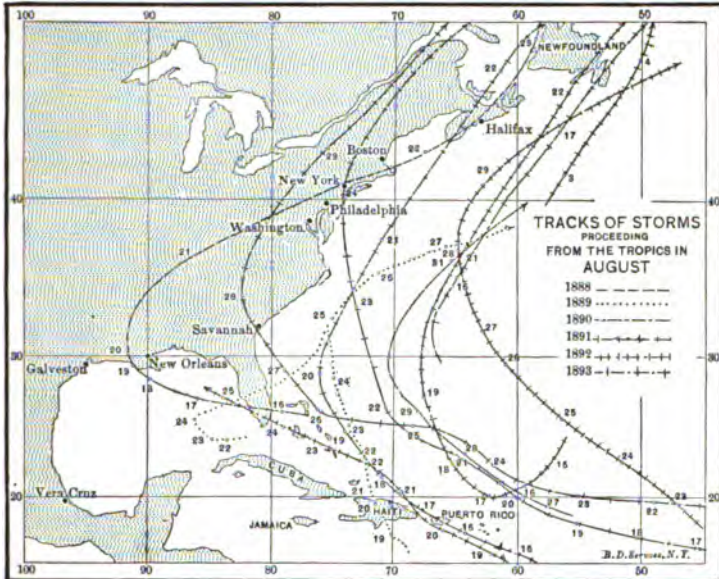


FIG. 45.

Tracks of August hurricanes, 1888-1893.

was destroyed, 176 lives were lost, a million dollars' worth of property was destroyed, and much destruction was done elsewhere along the coast. The same town was again devastated on August 19 and 20, 1886. On the Ganges delta, many hundreds of thousands of lives have been lost as a result of these waves. In one storm alone, that of October

31, 1876, 100,000 people were killed. Even along the Atlantic coast of the United States, where the hurricanes are of much less violence than in the tropics, a vast amount of destruction is done by them. Not only are ships destroyed, but the low coasts are swept by storm waves (Fig. 82), as has frequently been the case on the New Jersey coast and on the Sea Islands of the Carolina coast.

Path.—In the North Atlantic, the hurricanes usually move first toward the northwest, then they curve and pass along the Atlantic coast of the United States until the latitude of Cape Hatteras is reached, when they generally turn to the right and pass in a northeasterly direction out into the Atlantic, which they often cross (Fig. 45). However, at times they diverge from their path and enter the United States, passing northward into Canada. Thus, while we usually experience only the western part of the hurricane, at times the very center moves over the Atlantic coast states (Fig. 42). In the North Pacific, their path is about the same; but south of the equator, instead of turning to the right, they are guided to the left by the deflective influence of the earth's rotation and the prevailing westerlies.

The size of these storms varies very greatly; and while sometimes they are very large, the area covered by the violent portion of them is usually not more than one or two hundred miles in diameter. When most violent, the area of the hurricane is small, and this is normally the case near the tropics, not far from the place of origin. By the time they have progressed well into the temperate latitudes, their area is greatly increased, and they sometimes cover several hundred thousand square miles. At the same time their energy decreases, and they may even become worn out, so that they lose their distinctive features, particularly when passing over the land.

Time of Occurrence.—Another notable feature connected with hurricanes, is the fact that they occur most commonly in certain months of the year. Between the years 1493 and 1855, 355 supposed hurricanes have been recorded at the West Indies; and out of these, 287 occurred in four months, 42 in July, 96 in August, 80 in September, and 69 in October. In the regions south of the equator, the hurricanes come most commonly in the months of the southern autumn and late summer, or in other words in January, February, March, and April. In the North Pacific, the time of occurrence of the typhoons is the same as that of the Atlantic hurricanes. The so-called "*line storm*" of the Atlantic coast, which is expected about the middle of September, is in reality one of these hurricanes.

Cause.—In the explanation of hurricanes there are several peculiar features which call for consideration. We must bear in mind that the storms are whirling areas of air, in which the winds move violently in a spiral direction toward a center, which is a place of ascending air. The whirling of the winds is in a uniform direction (Figs. 41, 43, and 44), in the northern hemisphere being toward the left hand. The storms begin over the ocean and are by far the most abundant in the late summer or the autumn. Their path of progression is first toward the northwest, and then toward the northeast, after having curved around with a parabolic curve (Fig. 45). They are found most commonly in the northern hemisphere and appear to be entirely absent from the South Atlantic. Any explanation which does not account for these peculiarities cannot be satisfactory.

Since the storms are confined to the regions near the tropics, or occur outside of them only after having moved to the north or south, we naturally look to the heat of these regions as the cause of the storms. The warm air is ascend-

ing and winds are blowing toward the place of ascent. As a result of the *directly* inflowing air, a whirling cannot be produced; and some cause must be found which will originate the spiral motion of the air. A possible cause for this is the deflective influence of the earth's rotation; but ordinarily this can produce little effect near the equator, because the difference in the velocity of rotation of different latitudes in this belt is very slight (Fig. 21). Upon examining the temperature charts of the world, we find that the heat equator is farthest from the geographic equator in the late summer and early autumn, and that it migrates farthest from the equator in the northern hemisphere, while in the Atlantic it is never far south of the equator.

When the place of maximum heat is far from the equator, the influence of rotation will tend to turn the winds to the right as they blow in toward the place where the air is ascending. The farther these currents are from the equator, the more strongly is this tendency developed; and consequently those winds that blow toward the equator, are turned more than those that move in from the equator. Thus a whirl is begun, which in the northern hemisphere, always has its winds turning toward the left hand. This whirl may best be started in the summer or late autumn. The conditions are never favorable to the production of hurricanes in the South Atlantic, because the heat equator does not migrate far into that ocean.

The almost exclusive development of hurricanes over the oceans, is probably due to the presence of moisture-laden winds in these regions, as well as to the very uniform conditions that exist there. Water vapor is a great storehouse of energy, and it is estimated that the heat needed to form a pound of water vapor, would melt several pounds of iron.

When the vapor condenses, this heat adds to the energy of the storm, and thus violent storms form over the ocean, where there is much vapor in the air ; but over the land the conditions are not so favorable. The condensation of the vapor aids the air in rising, and the very rising causes the condensation of more vapor, so that air is drawn toward the center with great velocity ; and this is maintained for days, and possibly for over a week, by the constant supply of the necessary energy in the form of heat which was latent, and which becomes apparent when the vapor condenses. As the storm progresses into colder latitudes, its energy decreases, and in time it dies out.

We are able to find a satisfactory explanation of the path of the hurricane, in a combination of the prevailing winds and the earth's rotation. The storm starts in the trade-wind belt, but it rises above this belt into the upper air of the anti-trades. The one set of winds tends to blow the storm toward the southwest, the other toward the northeast (in the northern hemisphere), and the hurricane often remains nearly stationary for a day or two, as if in doubt which way to move. Eventually it begins to move in a northwest direction toward the land, and soon it comes under the influence of the earth's rotation and the prevailing westerlies. This increases in effect as the path more nearly approaches a northerly direction, and the storms generally turn in the latitude of the region between Florida and Cape Hatteras.

Temperate Latitude Cyclones: *Resemblance to Hurricanes.*—

In many respects these storms bear a resemblance to the tropical cyclones ; and until quite recently it was common among meteorologists to consider the two classes as related phenomena dependent upon similar causes. These storms are the ones which bring the greater part of the rain to the northern United States, and upon which depend most of

the weather changes of the northern temperate latitudes. The "northeast storms" of New England, so called because they bear damp northeast winds, belong to this class. Every part of the east experiences them, and their importance is very great.

So close is the resemblance between hurricanes and temperate latitude cyclones, that when the latter are violent, it

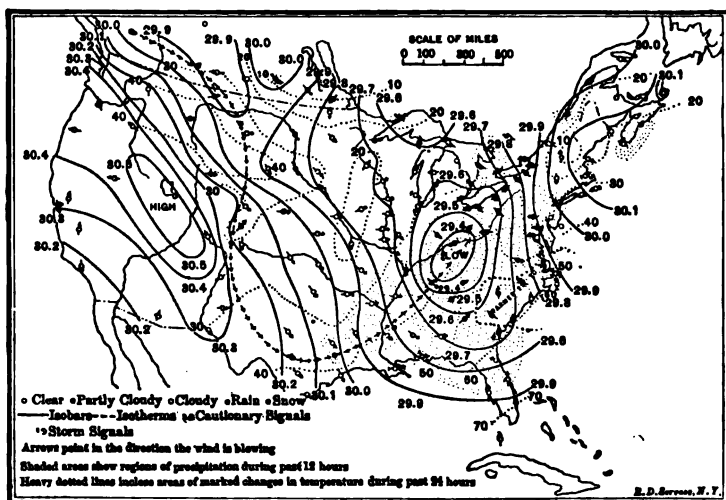


FIG. 46.

Map showing path pursued by a storm and the conditions which accompany it.

is quite impossible to distinguish the two kinds of storms. There is a resemblance in form, in winds, and in general behavior (compare Figs. 44 and 46). Both kinds of storms are great whirling masses of air, in which there are clouds from which rain falls; and the storm area progresses from one place to another. The winds move along a spiral track toward a central area of low pressure, where the air is apparently ascending. In a part of their course, where they

cross the North Atlantic, the paths of the two kinds of storms are practically the same (Fig. 48).

Differences from Hurricanes. — Notwithstanding these resemblances, there are so many differences that we are warranted in considering hurricanes and temperate latitude cyclones as separate phenomena. One of the most striking differences is that of size; for while the hurricanes usually

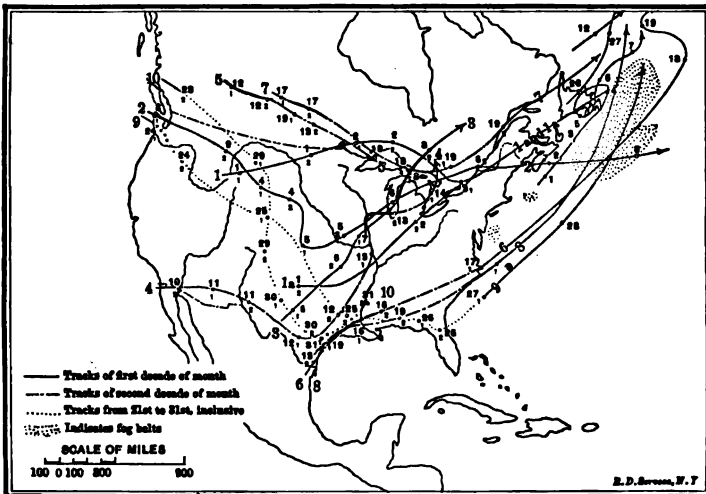


FIG. 47.

Paths of low-pressure areas, December, 1892. Large figures show the number of the storms, the small figures are days of the month.

begin as small storms, they may cover a large area when they have passed far into the temperate latitudes; but the temperate latitude cyclones may cover great areas even shortly after their formation. The cyclonic disturbances may extend over the entire eastern third of the country, from Canada to the Gulf, and from the Atlantic to the Mississippi. The hurricanes are most violent shortly after

they are formed, while the temperate latitude cyclones often develop violence as they proceed on their course. While cyclones may at times become very violent, they never attain the intensity which is noticed in some hurricanes. The whirling of the air in the temperate latitude cyclones is not so distinct as in the hurricanes (Figs. 44 and 46), and, in them, there is rarely if ever a distinct "eye."

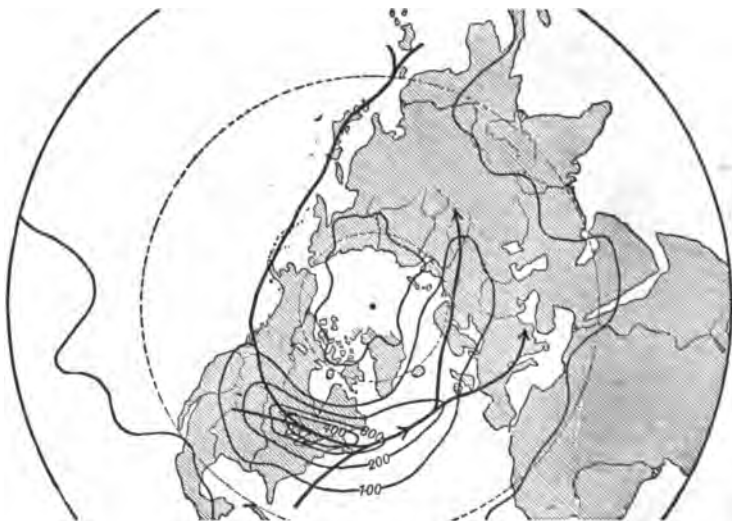


FIG. 48.

Average storm tracks. Relative abundance indicated by numbers showing the total number between the years 1878 and 1887.

While hurricanes are most commonly developed in the autumn, temperate latitude cyclones occur in all seasons of the year, but are most numerous and violent in the winter. They do not develop in tropical latitudes, but are formed in various parts of the temperate zone. Some of them begin in the Pacific Ocean, others start in the southwestern part of this country, while others are first noticed in the northwest.

Their path of progression does not show the peculiar curving so noticeable in the tracks of hurricanes; but their direction is usually toward the east or northeast (Figs. 47 and 49). If they begin in the Pacific or the northwest, they move in an easterly direction across northern United States or southern Canada; and the center very commonly passes over the Great Lakes and down the valley of the St. Law-

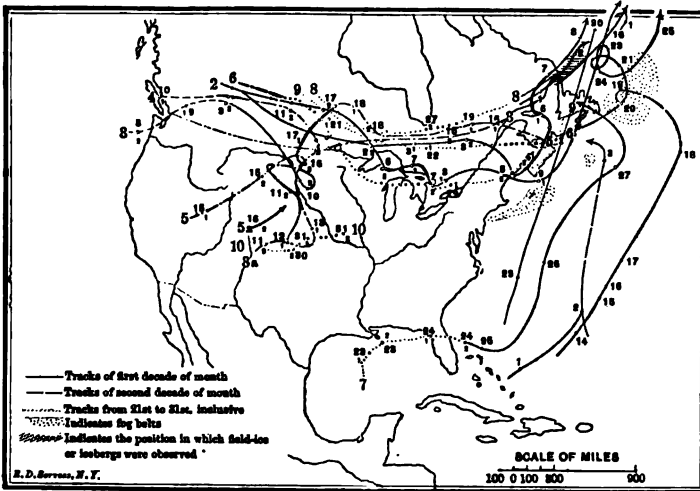


FIG. 49.

Tracks of low-pressure areas (both hurricanes and temperate latitude cyclones), October, 1892. Number of the storm indicated by large figures, dates by small figures.

rence. If they have their beginning in the southwest (Fig. 47), they first move northward, then curving to the right, they pass out upon the Atlantic.

The paths of the hurricanes, and nearly all of the north temperate latitude cyclones, converge toward the Nova Scotia-Newfoundland region, and then remain nearly parallel across the Atlantic. Sometimes these storms begin in the Pacific,

and pass across the United States, the Atlantic, and Europe, thus going nearly around the earth (Fig. 48). While the path of progression is usually regular, there are many minor irregularities of a peculiar and rather exceptional nature (Fig. 49). The origin of these is not well understood.

Effects. — The effects of these storms in northern United States are very important; and they are not confined to this region, but occur in Asia, Europe, and the south temperate latitudes. In the United States, the storms usually come from the west, and hence from the interior, while in Europe they come from the ocean. They bring to us the greater part of our rain and snow; they are the main cause for thunderstorms and tornadoes; they produce many of our most striking winds; and they are the cause for many of the changes in temperature which we experience. The warm south winds of the winter, and the heated spells and droughts of the summer, as well as the cold northwest blasts of winter, have their origin in these cyclonic disturbances. At times the violence of the cyclones is so great that much destruction is accomplished both on the land and on the water. They are particularly destructive on the ocean, and nearly every winter the fishing fleet and coasting vessels suffer from their destructiveness.

Winds. — The winds of the temperate latitude cyclones vary in force, as well as in direction. Some storms have gentle winds, while in others they are very violent; and in different parts of the same storm the velocity may vary greatly. On the land they are usually less violent than on the water, because the irregularities tend to destroy them by friction.

If a storm is passing over a given place, the direction of the wind changes during its progress; and the points of the compass through which the wind veers, depend upon the position of the storm center. If it is north of the place of

observation, the kind of change will be very different from that which occurs when the storm center is toward the south. The best way to understand these changes is to study the weather maps and notice the change of wind as the storms progress on their path.

Certain *special* kinds of winds are generated in cyclonic disturbances. On the southern side of a storm, warm winds are drawn in from southern latitudes; and in winter these may cause a snowstorm to change to rain. In Italy, these warm southern winds come from the heated desert region of northern Africa, and hence are usually dry. In that country they are known as the *sirocco*; and this same type of wind is also developed in the United States. Here, however, the *sirocco* is not dry, but is generally warm and often damp. In southern New England it brings damp air from the Atlantic Ocean; and this air is warm because it comes from the area influenced by the Gulf Stream.

A peculiar type of wind known as the *foehn* is developed in Switzerland, where air is drawn over the Alps by the passage of a storm center over central Europe. This air, drawn over the Italian side of the mountains, is caused to give up much of its moisture as it rises and cools. It is drawn down the northern side of the Alps with considerable velocity, and as it descends it warms dynamically. Therefore, the *foehn* is a dry and very warm wind, which in winter will often remove a layer of snow by direct evaporation. Its dryness is so remarkable that it has been thought to be a hot breath from the Sahara.

A similar wind is caused by the passage of storm centers east of the Rocky Mountains; and in that region it is known as the *chinook*. It is developed along the eastern base of the Rockies from Colorado to Montana, and its peculiarities are the same as those of the *foehn*. In the winter it often

causes an unseasonable rise in the temperature, and snow disappears before it with great rapidity.

On the western or rear side of cyclones, instead of warm there are cold winds. Here the air comes from cold northern lands, and in a measure also from the upper layers of the air. When very violent, these cold north or northwest winds are known as *blizzards*, and they often bear with them violent squalls of snow. The true home of the blizzard is the northwest; but even in the plateau region of central New York, true blizzards of a somewhat milder form, often succeed the severe winter snowstorms. In Europe, the same form of wind is developed; and in Texas the *norther* is a wind of similar origin.

Anticyclones. — Between well-developed cyclones, there are usually areas of high pressure, which are known as anticyclones. In these, the air is slowly settling¹ from upper parts of the atmosphere, and violent winds are not produced. The air is dry and clear, and hence radiation proceeds rapidly, so that at night the temperatures often descend to very low degrees.

While the air in these anticyclones is quiet, violent winds are often present at the margin, and particularly when the margins merge into the rear side of cyclones. Indeed, there seems to be a certain association between the cyclones and anticyclones, as if the down-settling air of the latter entered as a part of the whirl of the former. These conditions give us the *cold waves* of winter and the cool spells of summer (Figs. 63 and 64).

Cause. — Until recently it was quite commonly believed that the origin of temperate latitude cyclones was the same

¹ When air settles slowly, the dynamic heating is not marked. Hence this settling air in anticyclones usually reaches the earth with a low temperature; but there has been some warming, and the air is not so cold as when it started.

as that of hurricanes. In objection to this theory it may be said that convection does not seem capable of accounting for these great disturbances. In the first place, they cover an area often having a diameter of more than a thousand miles, but extend to a height of only two or three miles. Moreover, they are most violent and best developed in winter, when convection is least active. Recent studies seem to show that the cause for these storms is aloft, not at the ground.

While it cannot be considered proven that convection is not the cause, there are so many reasons for doubting this explanation, that it certainly cannot be accepted; and we are now without an explanation for these remarkable, though common, atmospheric disturbances. They pass across the country like a series of waves in the air; and it is possible that the great circumpolar whirl is thus thrown into waves, and that these disturbances are merely a secondary part of this planetary circulation. Recent studies seem also to show that there is some relation between them and magnetism; but we cannot feel certain of these suggestions.

The path followed by these cyclones and anticyclones is easily explained. They are borne along in the whirl of air which moves about the pole, and hence their direction is from west to east. As a result of the influence of the earth's rotation, upon the air currents the storms are carried along their regular paths. The winds in the storms cause a whirling in the same direction as that of the hurricane, and for the same reason, — those on the northern side are most deflected.

Secondary Storms. — Aside from the greater general disturbances, there are certain minor phenomena of cyclonic storms, which attract much attention because of their violence. The two most important of these are thunderstorms and tornadoes.

Thunderstorms. — When moist air rises as a result of

convection, if the ascent carries the air high enough for the dew-point to be reached, clouds may form and rain fall. In such cases electricity may be generated, and lightning and thunder may accompany the rain. In the belt of doldrums, the ascent of the moist air causes frequent thunderstorms during the day; and in summer, the rising air among the mountains may cause the formation of thunderclouds and rains. In this class of storm there is no distinct whirl, but a simple ascent of moist air.

In central and eastern United States, thunderstorms are



FIG. 50.

Photograph of a distant thunderstorm.

common in summer; and they also are the result of uprising moist air. That this is so, is shown by the fact that they occur almost exclusively in summer, and near the close of hot, sultry days. On these days, one

may often witness the development of such a storm, if the place of observation is sufficiently elevated to command a wide-extending view (Fig. 50). Clouds begin to develop; and if they are seen from below, their bases are found to be flat, marking the plane at which the rising air reaches the dew-point.

When seen at one side, mound-like masses of clouds, often of mountainous heights, are found to rise above the even base. If the observer is well to one side of the cloud, it will be noticed that as the storm develops, the form is quite like

that of an anvil (Fig. 50). At high elevations, the clouds extend out in front of the storm, marking the upper outflow of the air. The great elevation of the cloud mass is due to the fact that the air continues to rise to these heights, and the vapor to condense as the temperature descends.

Most of our thunderstorms are a part of moderately developed cyclonic disturbances, and they occur most commonly in the southern part of these storms. Here warm moist air is being drawn in toward the storm center, and hence the conditions favoring the development of thunderstorms are produced. As the storm center progresses, the area in which thunderstorms may develop also moves eastward, and any single storm will be found to have the same path (Fig. 51). Some thunderstorms have passed entirely across

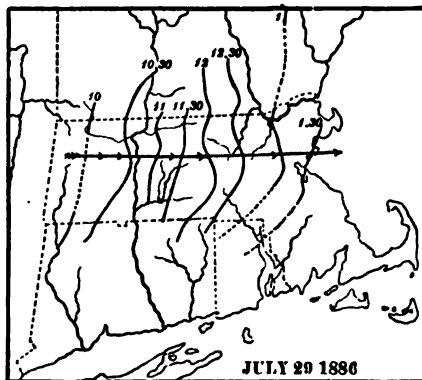


FIG. 51.

Progression of a thunderstorm in Massachusetts. The figures represent the hours at which the storm front reached the places indicated by the line.

New England, while others die out after traveling a few miles. Some pass over a broad path, while the width of others is only a few hundred yards. When the path is long, the storm may continue into the night; and most night thunderstorms have originated, during the preceding afternoon, at some point far to the west. The rate of progression is usually not greater than 40 or 50 miles an hour.

In the thunderstorm, after the first violent squall, that usually blows out from the base of the storm, the winds

are generally not violent; but there is a steady and often heavy downfall of rain, with accompanying thunder and lightning. In some cases the downpour of rain is excessive; and among the mountains of the west, there are often such torrents of water that the name *cloudburst* is given to them. The name is certainly warranted, for the water falls in sheets, in a manner which can be appreciated only after having seen one. These excessive rains may be due to a supersaturation of the air.

, *Tornadoes and Waterspouts.* — These extraordinarily violent storms are fortunately small, local, and not common in most of the country. Like the dust whirl of the desert, or like the hurricane, they are whirling bodies of air, in which the winds blow toward a center, where they rise (Fig. 52). The winds blow at such terrific rates that houses are torn



FIG. 52.

View of a tornado.

down and the parts carried away (Fig. 53). The newspapers furnish vivid descriptions of them; and while they are often exaggerated, almost no story concerning the action of tornadoes is too incredible for belief.¹

In the center, where the air is ascending, the air pressure is often so low that a partial

vacuum is produced; and the walls of houses may then be blown outward by the sudden expansion of the air within.

As the tornado approaches, it appears as a great funnel-shaped column of black cloud (Fig. 52), in which there are signs of violent commotion. As it comes nearer, a roaring noise is heard; and as the cloud overspreads the sky, rain or

¹ In newspaper accounts they are usually called cyclones.

hail falls ; but this ceases in the violent part of the tornado, where the air is rising so rapidly that these forms of water cannot descend. At first there is no wind, then suddenly a gale springs up, and almost immediately its violence becomes so great that houses and trees are felled. On opposite sides of the storm the wind moves spirally toward the center.

The tornado usually progresses at a rate of from 25 to 40 miles an hour. Its width is rarely as great as a mile,

and more often only a few hundred yards, or even feet, so that it cuts a swathe, on either side of which no destruction is accomplished. The distance traversed by one of these storms is generally not more than 30 or 40 miles, and it rarely lasts more than an hour. They do not occur in large numbers outside of the central states of the Mississippi valley, although they do occasionally occur in the east. West of Dakota they are not known. They not uncommonly occur in association with thunderstorms ; and like these, they come after hot, sultry days, in areas covered by the southern portions of cyclonic storms. Their movement is almost invariably eastward.



FIG. 53.

Effect of a tornado at Lawrence, Mass., July 26, 1890.

In part at least, tornadoes are due to convection ; and the reason for their abundance in the Mississippi valley seems to be that warm, moist air is drawn up that valley toward the

storm center, while above it there is a colder layer of eastward moving air. Therefore the conditions of the atmosphere are peculiarly unstable; and the increased heat caused by the sun, starts an overturning which soon takes the form of a violent whirl. This is not possible in the far west, where

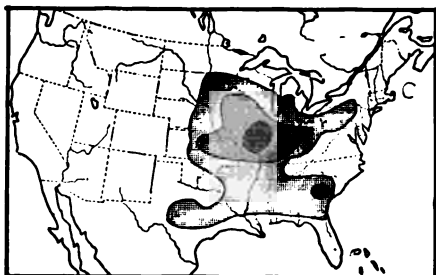


FIG. 54.

Distribution of tornadoes 1794-1881, the intensity of shading showing greatest abundance. Darkest more than 35, medium shade 25-35, lightest shade less than 25.

the lower air is dry; and in the east, the atmosphere is rarely in a sufficiently unstable state for this violent overturning.

When the tornado develops or passes over the sea, or over a large lake, it takes the form of a *waterspout*. It is doubtful if these waterspouts are col-

umns of water, as is often stated; but there is probably a conical wave in the center.

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- Davis.** — WHIRLWINDS, CYCLONES, AND TORNADOES. Lee & Shepard, Boston, 1884. 24mo. \$0.50. (Reprinted from "Science.")
- Finley.** — REPORT ON THE CHARACTERS OF SIX HUNDRED TORNADOES. Professional Papers No. 7, U. S. Signal Service, Washington, 1884.
- Finley.** — TORNADOES. Hine, New York, 1887. 12mo. \$1.00. (Based mainly upon previous publications in the U. S. Signal Service Reports, etc.)
- The MONTHLY WEATHER REVIEW and the DAILY WEATHER MAPS, published by the Weather Bureau at Washington, and the PILOT CHARTS, published by the Hydrographic Office of the Navy Department at Washington, will be found invaluable in laboratory instruction. Teachers who are interested can probably obtain these upon application.

CHAPTER VI.

THE MOISTURE OF THE ATMOSPHERE.

Dew. — When the temperature of the air descends far enough, a point is reached when there must be a condensation of some of the contained moisture, because the ability of the air to carry water vapor, depends in large measure upon the temperature. With dry air, the temperature must be lowered much farther than with damp or humid air; and on the sultry days of summer, a pitcher of ice water lowers the temperature of the air in contact with it sufficiently to cause the condensation of some of the vapor on the outside of the pitcher, which is said to “sweat.”

When the ground becomes cold at night, the lower air is also cooled, and that which is in contact with the ground may give up some of its vapor as dew. The temperature at which this will happen, naturally depends upon the amount of vapor in the air; and in the tropics, where the hot air is very humid, the amount of dew that forms at night is often very great. Even the coolness of the late afternoon is often sufficient to cause the condensation of dew in the tropics; and during our own summer days, one often notices that the grass is wet with dew even before dark.

Dew forms most readily on those bodies that cool by radiation most quickly. Thus grass and leaves are dew-covered sooner than soil. During some nights, even when the air is quite humid, dew is not formed. By interfering with radiation, clouds tend to prevent the formation of dew; and as a

result of the stirring of the air, and the inflow of new supplies of air, wind tends to check dew formation. Because the air is more humid, dew is formed more readily near streams or swamps than in dry places. Dew is heavier in valleys than on hills, partly because of the greater dampness of the valleys, partly because cold air slides down into them from the hillsides, and partly because the air in valleys is more quiet than that on the hilltops.

While the main cause for dew seems to be condensation of vapor from the air, recent studies show that this is not the only cause. At all times plants are furnishing moisture to the air by transpiration. Ordinarily this is evaporated; but at night this evaporation is checked, when the air is cooled, and its power for evaporation reduced because it is either saturated or has a high relative humidity. Then the moisture forms drops of water on the leaves. Thus dew is a result of the combination of two processes, in both of which the cooling of the air by contact with the earth is the important cause.

Frost. — When the temperature of the dew-point is below freezing, the condensation of vapor takes the form of frost. It is not frozen dew, but vapor that has become condensed as a solid, instead of a liquid. In cause, and in occurrence, frost may be described in the same terms as those used in the description of dew. However, the effect of frost is quite different, for it causes vegetation to suffer, while dew refreshes vegetation. Frost is not likely to occur on windy or on cloudy nights, and it comes earlier in damp valleys than on dry hilltops. This is why the autumn foliage first assumes its brilliant tints in the swamps. A covering, such as a sheet, by interfering with radiation, will prevent a light frost; and in this way delicate plants may be protected when there is danger of frost.

Fog.—This is merely the condensation of water vapor into the form of very tiny drops, which are so light that they do not readily fall to the ground. When we breathe the warm moist breath into the cold air of a winter day, we produce a tiny fog. Many of the great ocean fogs owe their origin to a similar cause. On the banks of Newfoundland, where the warm Gulf Stream is side by side with the cold Labrador current, fogs are produced when the winds of the one region pass over the other. Very extensive fogs are thus caused, and this has made that part of the Atlantic famous. When warm air is drawn northward toward storm centers, fogs are particularly liable to occur here. These and other ocean fogs often extend upon the land, as for instance on the coasts of Maine and Nova Scotia.

A fog sometimes surrounds an iceberg, because the air around it is chilled. Over the surface of lakes we sometimes see fogs developed by the chilling effects of air currents. At times the cool water produces a fog by contact with warm air. In damp valleys, a valley fog is often formed when the air is chilled and the vapor condensed into particles. This is particularly liable to happen during nights when the conditions favoring a heavy dew are present. Every one must have noticed the cool dampness of valleys, which is so noticeable in passing along a hilly road just after nightfall. This often increases until some of the dampness forms into fog particles. One often sees valley fog among the mountains (Fig. 55), and many clouds are nothing but fogs. As one looks down upon a valley fog, there is a white rolling surface, above which may rise the tree tops or church steeples, while everything else is hidden. The appearance is not unlike that which one sees in the mountains when above the clouds.

By furnishing a nucleus about which the vapor may con-

dense, "dust" particles are important in the formation of some fogs. It is believed that the fogginess of London in part depends upon the large amount of dust in the air.

Haze. — At times, and particularly during dry weather, a thin veil of blue haze extends through the atmosphere and partly obscures the distant landscape. Often it is so indistinct that one notices it only when an unobstructed view



FIG. 55.

Valley fog in the Himalayas. Mount Everest in the background.

of far-distant hills is obtained; but during some days it becomes so thick and dense, that points near at hand are almost completely obscured, and even the sun loses its intensity, while the sky becomes dull. Haze is not damp like fog, and there is reason to question whether it is often due to water particles. Probably the greater part of the haze results from dust in the air; and during droughts the air is often very hazy, because at such times rains have not

occurred to clear the sky, and the air is often supplied with much dust from forest fires.

Mist. — At times the air is filled with minute particles of water, which are larger than those in a fog, and which therefore cause greater dampness. The mist is intermediate between fog and rain, and possibly it is made of numerous fog particles which have united.

Clouds. — Clouds are composed of particles of moisture due to the condensation of water vapor. Sometimes these particles are very small, like those in fog, at other times they are made of mist, or even of raindrops, and in many cases of ice particles or snow crystals. They are formed when-

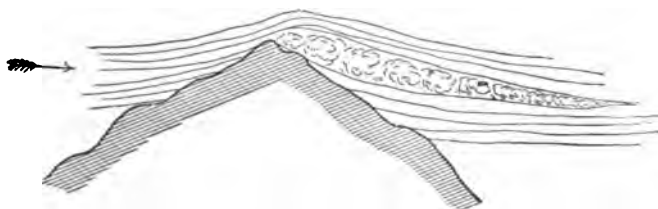


FIG. 56.

The banner cloud, caused by a moist wind blowing against a mountain peak.

ever vapor-laden air has its temperature lowered to the dew-point; and this may be caused in several ways.

When damp air encounters a cold mountain top, clouds are formed, and these may surround the mountain peak or extend beyond it like a banner (Fig. 56). Where high mountains extend upward in the path of the trade winds, these banner clouds are often produced. Air that is caused to ascend, frequently has its temperature lowered below the dew-point; and when this point is reached, clouds are formed. This may happen when air rises by convection, or when it ascends land elevations. During the summer, and in mountains, such clouds are commonly formed. The mixture of air of

During stormy weather, when clouds are low, we may find ourselves enveloped in a true cloud mist. The forms of clouds are very beautiful and varied, and the various kinds are known under different names. The



FIG. 57.

Photographs of five common cloud forms.

<i>Nimbus</i>	<i>Cirrus.</i>	<i>Cumulus.</i>
<i>Cirro-cumulus.</i>		<i>Cumulo-stratus.</i>

during storms, when the clouds are low, we may find ourselves enveloped in a true cloud mist.

The forms of clouds are very beautiful and varied, and the various kinds are known under different names. The

following is a classification of clouds based partly upon their form and partly upon their elevation : —

CIRRUS.	CUMULO-STRATUS.
CIRRO-STRATUS.	NIMBUS.
CIRRO-CUMULUS.	STRATUS.
CUMULUS.	

The *cirrus* cloud (Fig. 57) is the highest form known, its elevation often being greater than five miles. It is so high that the condensation of water vapor forms ice spicules, and this is the reason why these clouds appear thin, white, hazy, and almost transparent. They drift along at very rapid rates, and in northern latitudes usually move toward the east, being carried along in the circumpolar whirl. Their form is variable and often remarkable. They are commonly produced by the upper outflow of air in a cyclonic storm.

At times the cirrus clouds occur in the form of distinct bands, and they are then known under the name of *cirro-stratus*. This form of cloud may completely overspread the sky, but its transparency is so great that the sun is visible through it, and during such conditions of cloudiness halos and coronas are commonly formed. Many varied forms of cirrus clouds are recognized, and various names are given to them. Sometimes they are frayed and torn as if by violent air currents. At other times they occur in bunches, arranged often in lines, as if produced by waves of the air, the groups of clouds resembling a choppy sea. When these bunches of upper air clouds are quite distinct, they are known as *cirro-cumulus* (Fig. 57). Oftentimes the sky is speckled with these clouds, and then sailors call it the mackerel sky.

Among the most beautiful of clouds are those known as *cumulus* (Fig. 57). They are produced at a lower elevation than the cirrus, and are often composed of fog particles in-

stead of ice. When best developed, as is the case in summer, they are the typical thunder heads, which rise from a flat base, at an elevation of about a mile, and extend into the air, often to a height of several thousand feet above this. They consist of a mass of rounded, dome-like clouds, which often produce a very fantastic and beautiful effect, particularly when lighted by the rays of the setting sun.

These clouds are common, every-day occurrences in the belt of calms, and in summer they are often produced around mountain peaks, and over the heated lowlands. In these cases their cause is the ascension of warm moist air; and during hot summer days they may often be seen to form. Over the land, they are much more readily formed than over the water, and the presence of land is often indicated by their occurrence. When sailing along the coast of Florida in summer, the position of the land is often shown by a line of these clouds. At nighttime, when convection ceases, the clouds melt away and the sky clears.

Clouds that resemble the cumulus, but differ from them in being more massive and banded, are known under the name of *cumulo-stratus* (Fig. 57). When this form of cloud is very massive, so that large parts of the sky are covered, the name *stratus* is applied. These often entirely overspread the sky, forming a gray, illy-defined cloud mass. Their elevation is usually between 600 and 3000 feet, but at times they are so low that they touch the earth. This is the kind of cloud that occurs during cyclonic storms, and then they may cover the sky over an area of thousands of square miles. When rain is falling from a cloud, it is known as *nimbus* (Fig. 57).

Rain.— There is every gradation between dew and rain, and raindrops are often made by the union of numerous fog particles. The exact means by which these particles are gathered together, cannot be stated; but perhaps in many

cases it is the result of the contact of particles driven against one another by wind, or as a result of their descent through the air.

There is a very definite relation between clouds and rain, and the causes which produce the one form the other. The most important of the causes are the mixture of currents of different temperature, the uprising of air, and the contact of warm moist air with cold land surfaces. The greater part of the rain of the world falls either (1) from cumulus clouds, or (2) from cyclonic storms, or (3) where moist winds blow from the water upon the



FIG. 58.

Photographs of actual snowflakes.

land. Away from places where these conditions occur, the rainfall is usually light. Sometimes, though rarely, rain-drops fall from a clear sky.

Snow.— This is the crystallized form assumed when water vapor condenses at temperatures below the freezing-point; and the forms thus produced are often very beautiful and fantastic (Fig. 58). There is an intimate relation between snow and rain, and the same storm may produce snow on the highlands and rain on the lowlands. Many of our winter rainstorms are due to the fact that the snow crystals have been melted in their downward passage; and the damp snows are a partial step in this direction (Fig. 59). The difference of a few degrees thus produces a very marked change. In the one case rain falls and speedily flows away,

while in the other case a cold covering of solid snow is laid upon the land, perhaps to stay for months. The clouds of the upper air are mostly made of ice or snow, and mountain peaks that extend into these upper layers, rarely receive any other form of precipitation.

Hail.— At times, particularly in summer, balls of ice known as hailstones fall from the clouds, especially from



FIG. 59.

Photograph taken after a fall of damp snow, showing how it clings to vegetation.

those accompanying thunderstorms and tornadoes. They are usually oval or rounded in form, and are often made of successive shells of clear and clouded ice. The mode of formation is not known; but there is some reason for believing that they are formed in violently moving and rising air currents, and that this is the reason why they so commonly fall on the margins of rather violent storms.

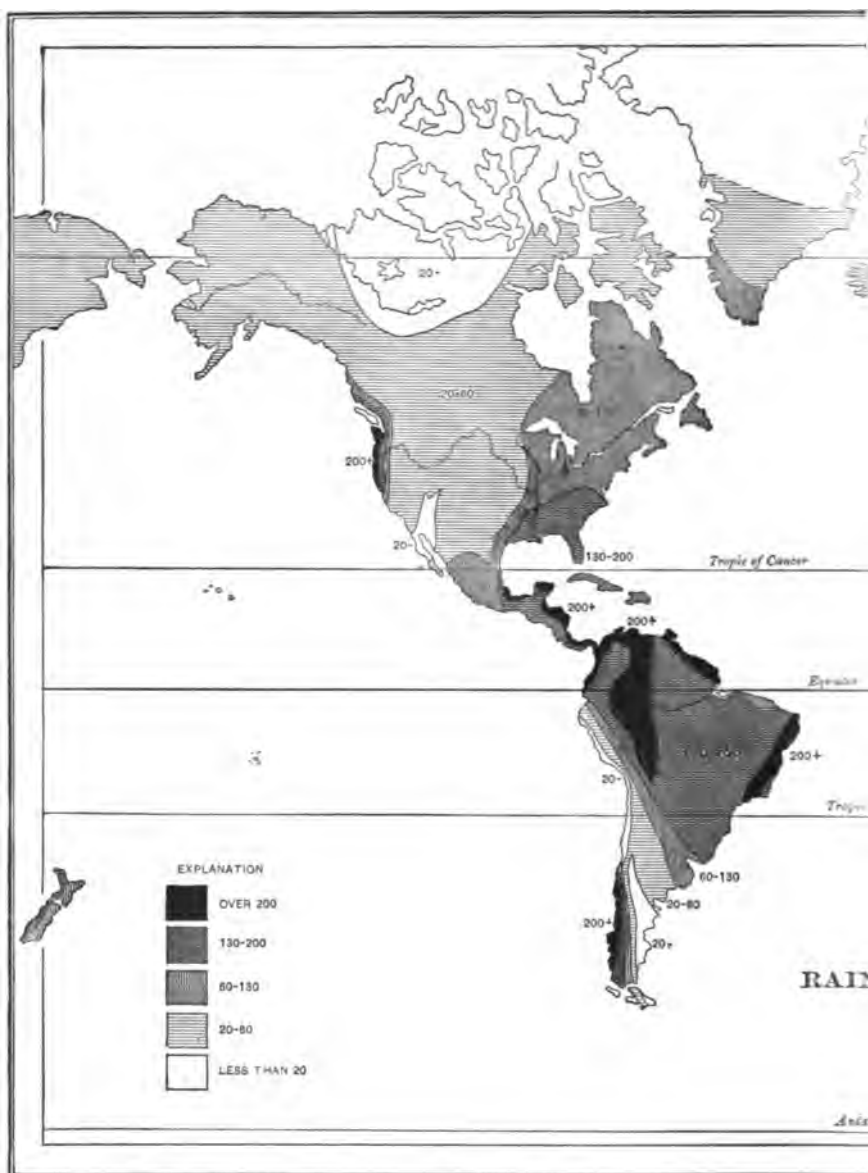




PLATE 12.
Annual rainfall of the world.

Distribution of Rainfall in the World. — As used here, the term rainfall includes both rain and snow. In general there is a difference in the amount of rainfall according to latitude and altitude. Since in high latitudes and high altitudes the temperature of the air is low, and therefore contains little vapor, the amount of rain that can be condensed in these places is less than in the warm tropics, where the air is humid. Still, there is much variation in this respect, as will readily be seen by a glance at Plate 12.

Without entering into the subject in great detail, a few notable facts shown on this chart may be pointed out. It will be noticed that in the belts where the trade winds blow *upon* the land, the rainfall is heavy, while in those places where they blow *over* the land, the rainfall is slight. Thus, as a result of this, the dry desert of the Sahara exists in the same latitude with several very rainy districts.

Where the winds blow against steeply rising mountains, such as the Himalayas, the precipitation is very heavy. Even outside of the trade-wind belt, when the winds blow from the warm ocean upon the land, the amount of rainfall is often very great. If mountains intercept these winds, they are drained of their moisture, and pass to the opposite side as dry winds, producing deserts. Thus there are two important causes for deserts.

In the belt of calms, where the air is almost constantly rising during the day, the precipitation is quite uniformly heavy; and as these belts migrate, the rainy conditions are carried with them. Thus we may have one very wet season, and an opposite dry season, when the calms are replaced by the trades. This is the case on both sides of the equator in Africa and South America.

Usually the rainfall is heavy near the coast; but where this is not the case, the winds are blowing from the land to the

sea. With the seasonal change in the wind direction, some coasts have a dry and a wet season. In the interior of continents, a condition of relative dryness usually prevails. This is not always a true desert condition, but often one of semi-aridity, in which the rainfall is not sufficient for successful agriculture. There may be every gradation between the humid country and a desert, passing through the stages of semi-aridity and the climate in which droughts are common.

The greatest irregularities of rainfall are noticed in temperate latitudes; and these depend in part upon the winds, the topography, the neighborhood to the sea, and the occurrence of cyclonic storms. In parts of the area, nearly the entire rainfall comes in association with these storms. Bearing in mind the previous discussion of temperature, winds, and storms, the student will be able to understand most of the irregularities in rainfall distribution indicated on the accompanying charts.

Distribution of Rainfall in the United States.—In this country (Plate 13), most of the features noticed on the rainfall charts of the world are well illustrated; but we have not the tropical conditions. On the Texas coast, the inblowing trades of the summer cause a heavy rainfall; and in Florida, much of the rain depends upon the neighborhood of the warm ocean waters. The rainfall of the eastern coast is less than that of the western, because in the former the winds are mostly from the land. Still, because this region is frequently visited by cyclonic disturbances, there are no deserts produced in the east.

From Florida to Maine, the rainfall decreases quite uniformly, as it should in passing from warm to cooler regions. On the western coast, the reverse is true, and the most humid part is in the north, while the southern portion is quite

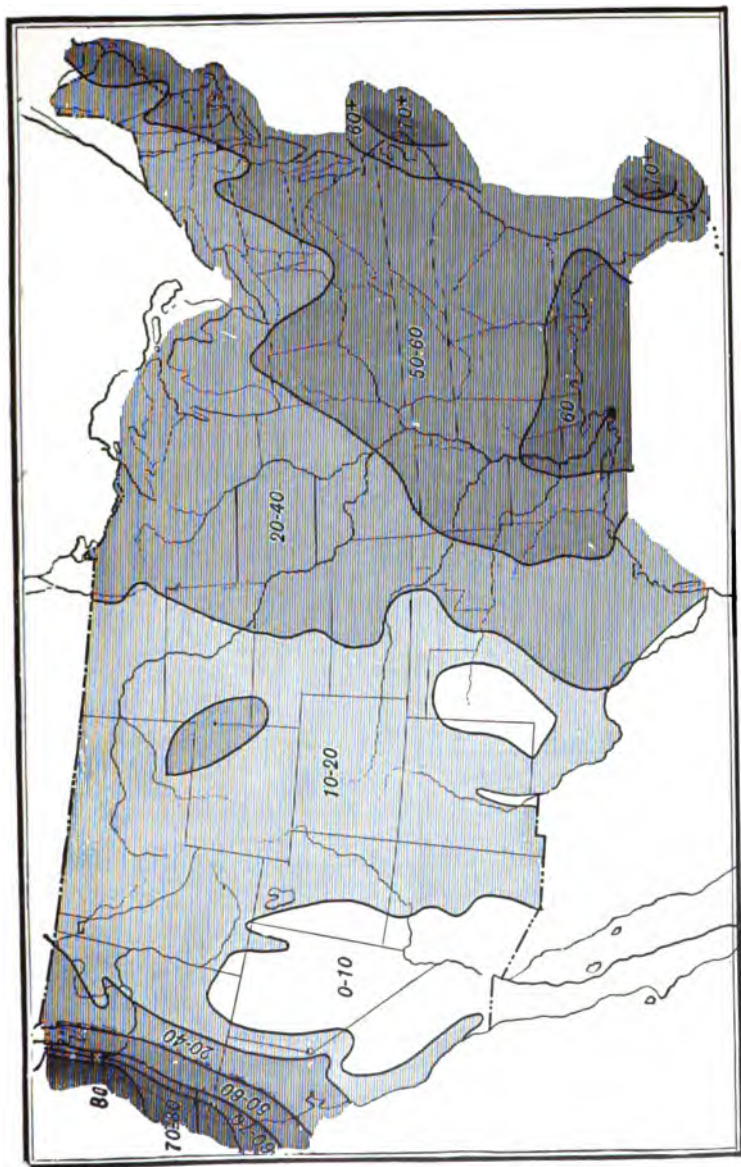


PLATE 13.
Rainfall of the United States, in inches.

arid. This is due to the fact that in the northern part, the winds blow from the ocean against the mountains.

Because of this, the rainfall also decreases very rapidly from the immediate coast toward the interior. Beyond the mountains of the coast, the country is either arid or in a truly desert condition; and this extends even to the plateau states east of the Rocky Mountains. Throughout the greater

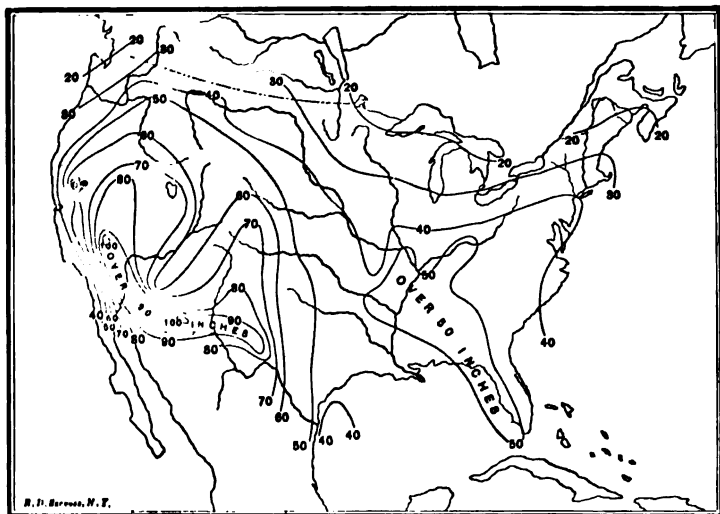


FIG. 60.

Rate of evaporation in the United States. Based upon observations for a year, in 1887-1888.

part of the western half of the country, the rainfall is very slight, because there are no great water bodies to supply the winds with moisture. Even in the states just west of the Mississippi valley, the rainfall is light and quite irregular, because the winds are dry. Here evaporation is rapid, and in some parts, where the total annual rainfall is less than 10 inches, it amounts to 100 inches (Fig. 60).

Distribution of Snowfall. — Over a very large part of the earth's surface snow is impossible, and a considerable part of the human race has never seen it. In the United States, snow falls nearly everywhere except in Florida and southern Texas and California; but it is only in high temperate and Arctic latitudes that much snow can fall upon

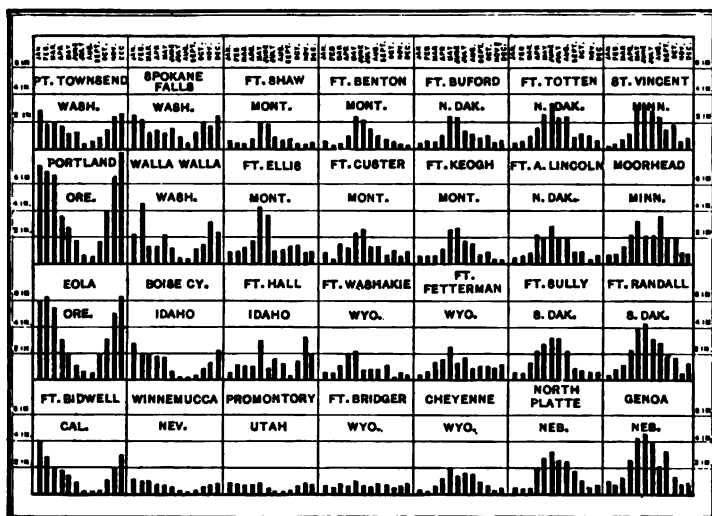


FIG. 61.

Monthly rainfall in the West, showing the heavy winter rains of Washington, in contrast with the normal condition of heaviest rainfall in summer. Also showing differences in amount in inches of rain.

the lowlands. Even under the equator it may fall on high mountain peaks. There is much variation in the distribution of snow, both from season to season, and from place to place.

Where the temperatures are low, the snow remains upon the ground during the winter; but in many places it stays only for a short time. In high mountains, where the snowfall is great, and where there is very little melting, it may

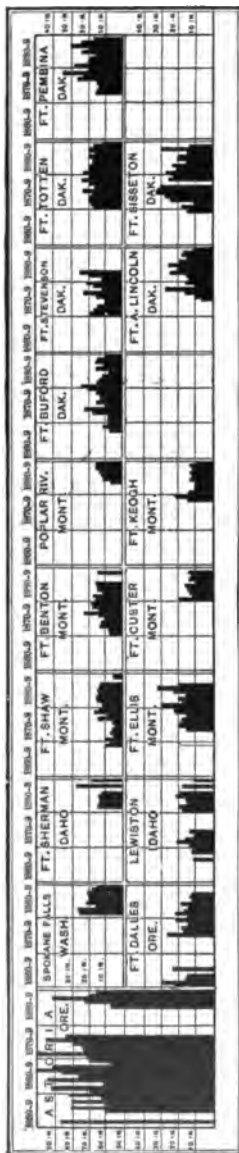


FIG. 62.
Annual variation in rainfall at several stations in the West in inches.

produce glaciers as a result of the accumulation of many winters' snow-fall. The same is true in parts of the Arctic and Antarctic lands, and in these cold places, even the summer precipitation is mostly in the form of snow.

Seasonal Distribution of Rainfall.

— Many parts of the earth have dry and wet seasons; and as has already been explained, this is usually due to a change in wind. In equatorial Africa, among the headwaters of the Nile, the migration of the belt of calms causes such a condition, and the same is true of the llanos of Venezuela and the campos of Brazil. The blowing of the monsoons upon the coast of Asia, and elsewhere, causes very rainy conditions which are quite absent when the monsoon winds blow from the land. At Cherapunji, where the rainfall is as great as 500 inches a year, the amount falling in December is only 0.2 inches, while in July it is over 130 inches. This excessive rainfall, which is the greatest on the earth, is caused by the blowing of the monsoons against a steeply rising mountain face. On the western coast of the United States, particularly in Washington and Oregon, the winter rainfall is

heavy, while in summer it is light (Fig. 61). This is due to the damp winter winds from the Pacific.

In the central and eastern states, the distribution of rainfall is very irregular, and it depends upon the nature and frequency of cyclonic storms. Some seasons are very dry, and then droughts may occur; but there is no regularity in the recurrence of these periods. Fig. 62 illustrates this variation in the western states.

Irregularities of Rainfall. — The normal rain is a steady and rather quiet downpour; but at times, particularly in connection with thunderstorms, the rainfall may be very heavy, and then more rain may fall in a few minutes than during an ordinary cyclonic storm lasting for a day or two. For instance, at Syracuse, New York, 8 inches of rain fell in one day, June 8, 1876; and in June, 1886, over 21 inches fell in 24 hours at Alexandria, Louisiana. The effect of such a sudden deluge of water in swelling the streams and wearing away the land is very important. The cloud-bursts of the Rocky Mountains furnish other instances of very remarkable rainfalls occurring in a short period of time. Where the rains are excessive in violence, the soil is sometimes washed away from steep slopes, leaving the bare rock exposed to the air. This is the case in that region of remarkable rainfall in India.



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CHAPTER VII.

WEATHER AND CLIMATE.

Weather. — Climate is the sum and average of weather, which includes the daily change in temperature, pressure, wind, rain, etc. The climate shows the general condition, while weather deals with the special instances of changes in the atmosphere. The data obtained in a study of the weather furnish the basis for a knowledge of the climate, and thus the two subjects grade into one another. Already, in the previous pages, much has been said concerning weather and climate;¹ but now a few statements upon the subject are made as a kind of summary.

Tropical and Arctic. — There is much difference in the variety of weather in various parts of the earth. Over the ocean, the weather conditions are less variable than on the land, and the greatest variation is found in temperate latitudes. Day after day, the weather in the belt of calms is nearly the same, the clear nights being followed by cloudy days with frequent rains, and the temperature being high and not very variable. In the belt of trade winds, the air moves rather steadily toward the equator, and the temperature is high. When these winds blow over the land, their dryness produces desert conditions; and when they blow upon the land, heavy rains are caused. Thunderstorms

¹ Many of the foregoing figures and plates illustrate this chapter as well.

may occur, and now and then a hurricane may develop, bringing with it violent winds and heavy rains.

In the polar regions the winter season is marked by uniform cold, and the storms always bring snow. During the summer there is no marked day and night alternation in temperature; and although the air is warmer than in winter, the temperature is uniformly low and snowstorms may occur.

Temperate Latitude Weather.—Taking the United States as typical of the temperate latitudes, we will examine the weather conditions of several sections. On the Pacific coast, north of central California, the days of summer are dry and warm, and the nights become quite cool. In the winter the warm winds from the Pacific blow upon the land, producing frequent rains during the day; but the temperature of the day, and even of the night, is moderate.

In the high mountains east of this, the air is cold, and even the summer storms often produce snow instead of rain. The temperature of day and night is low. In the desert regions between the mountains, storms rarely occur, and the air is quite constantly clear and dry. Occasionally, especially in summer, there are heavy thunderstorms, particularly among the mountains; but in some of the deserts, as for instance that of Arizona, there is almost no rainfall (Plate 13). During the summer day, the ground and air become highly heated, and at night low temperatures are produced by radiation.

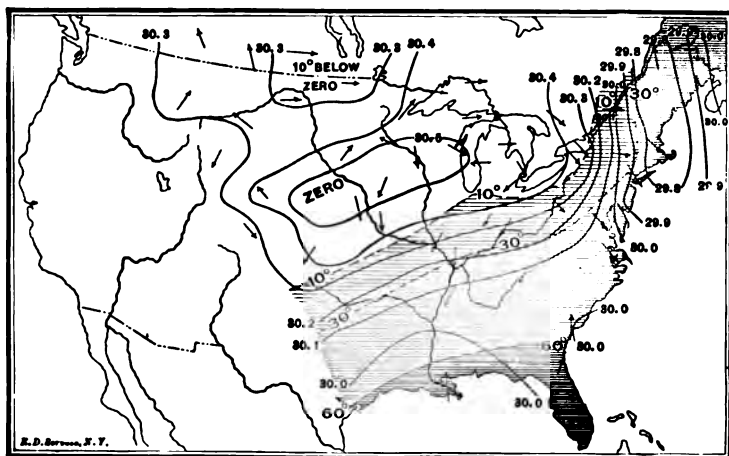
On the plains of Dakota, Montana, Manitoba, etc., the air is prevailing dry; and during the summer, the temperature of the day becomes high, while the nights are cool. During the winter, excessively cold spells are liable to occur, and temperatures as low as -30° are not uncommon. This region is subjected to the influence of cyclones

and anticyclones, with their accompanying conditions of rain or clear weather and variable winds. During the winter, there may be very heavy snowstorms, and at times extremely violent blizzards; and, following these, the warm chinook wind may cause an unseasonable rise in temperature. Farther south similar conditions prevail, but the weather changes are less intense. On the dry plains of Texas, the temperature ranges are extreme; but neither the chinook nor the blizzard occurs, though a cold norther sometimes produces a very severe weather change.

Along the coast of the southern states, high temperatures are experienced, and the ranges from season to season, and from day to night, are not great. Rainstorms are produced by the blowing of the winds from the warm ocean upon the land; and in the autumn, violent tropical hurricanes often visit the coast. No snow falls, but during the winter, when a cold wave spreads over the country, freezing temperatures may at times extend into this belt.

In the more northern states of the Mississippi valley, the weather of the winter is cold, snowstorms accompany cyclonic disturbances, and extremely low temperatures are produced during anti-cyclonic conditions. There are great daily temperature ranges, as well as some of an irregular nature. During the summer, cyclonic storms are less common, and they come at irregular intervals, and there may be long periods of drought. These droughts occur when the cyclonic disturbances are of moderate intensity, and the storm centers far to the north, in the Canadian territory. During these conditions, warm air is drawn in from the south toward the storm center, and this raises the temperature but does not produce rain. Under favorable conditions, thunderstorms and tornadoes may arise during the passage of low-pressure areas.

In southern Canada, New York, and New England, the weather is very variable and irregular. In the winter, snow-storms occur, and these are sometimes very heavy, particularly in the northern part of the area. Over a large part of the region, storms are of sufficient frequency, and the cold sufficiently intense and uniform, to allow the snows to accumulate during the winter and remain upon the ground



which radiation proceeds with ease, giving us our coldest winter weather; but the cold is not so intense as in the dry interior area of the northwest.

In the summer, storms are less frequent and less violent; but still they produce an effect upon the weather. When they are not intense, the warm air drawn in from the south, produces days of excessive heat and sultriness, during which thunderstorms may come; or a continuation of this condition may cause summer droughts. Along the seacoast, fogs are sometimes blown in upon the land, or the cool sea breeze may temper the heat of the summer day (Fig. 39). Well-developed cyclonic storms may arise; and in the autumn

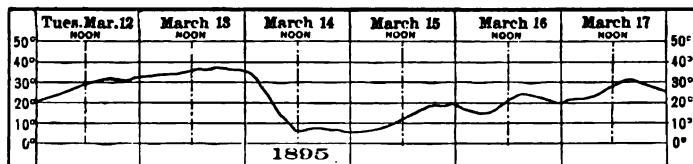


FIG. 64.

Sudden descent in temperature during passage of a cold wave at Ithaca, N. Y.

these become more frequent, and the region may then be visited by one of the West Indian hurricanes. During both summer and winter, the winds are very variable in force and direction.

This, which may be considered the typical weather of the temperate latitude, has for its main feature extreme irregularity and variability. From place to place there is much variation; and even at the same place, the weather of successive years is quite different. These are essentially the conditions that prevail in Europe; but here the winds are damper because their prevailing direction is from the west, and hence from over the Atlantic. Since there is less land,

there is much less variability in the weather conditions of the temperate latitudes of the southern hemisphere.

Climate. — The earth may be divided into climatic belts, the three primary zones being based upon difference in latitude, and hence in supply of solar energy. These zones are

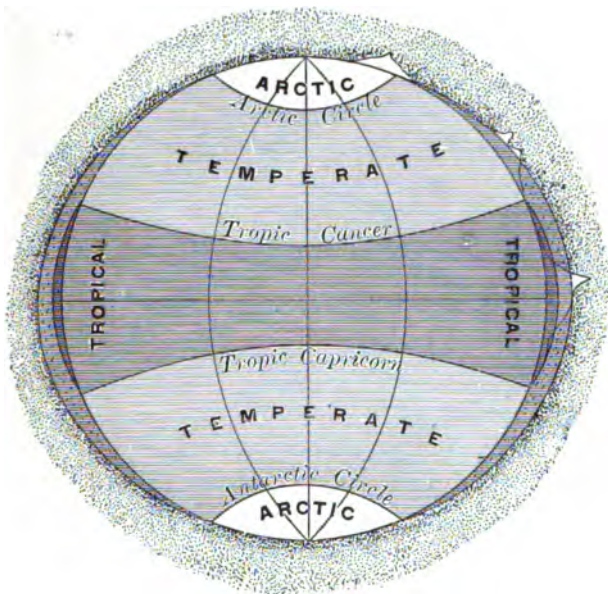


FIG. 65.
Climatic zones.

the tropical, temperate, and arctic (Fig. 65). Speaking generally, the tropical climate is characterized by high temperatures throughout the year, the arctic by low temperatures in all seasons, and the temperate by variability, and a marked change in the two opposite seasons of summer and winter. There are many exceptions to this general state-

ment, and each zone must be subdivided into oceanic, insular, interior, and upland climates.

Tropical Climate.— Between the tropics, the climate of the oceans and coasts is mostly warm and equable. The rainfall is considerable, though to this there are numerous exceptions, as for instance on those coasts from which the trade winds blow toward the sea. The doldrum belt is one of excessive rain and very uniform conditions of temperature; but that of the trade winds has a more variable climate. In the interior of the continents, there is much variation, though the uniform condition is that of high temperature. The temperature ranges are greater than on the ocean, and the average temperature is also higher.

There is every gradation between the regions of heavy equatorial rains, and deserts. In the belt of calms the rains are heavy, while in the trade-wind belts, the dry, south-moving winds often produce a truly desert condition. Thus the desert of Sahara, with a rainfall of less than 20 inches, and in some places with almost no rainfall, is on the same latitude with the region of eastern Central America, where the rainfall is over 200 inches. In the narrow zone which is alternately occupied by the belt of calms and the trade winds, the climate of one season is dry, and that of the other is very damp.

As a result of the monsoon condition, a peculiar climate is produced in India. There are three seasons: one cool and dry, when the winds blow from the interior; the second hot and dry, when the sun's heat becomes intense; and the third a wet season, when the monsoons blow upon the land.

Temperate Climate.— For the most part, the climate of the north temperate zone is very variable, and the year is divided into two seasons of extremes,—the summer and the winter, — with intermediate seasons of spring and autumn, which are

gradations between the summer and winter. However, this belt is divisible into several minor zones, of which we may consider five: the west coast, the east coast, the interior, the mountain, and the inter-montane zones.

The climate of the west coasts is comparatively equable and damp, because of the influence of the ocean, from which the winds blow as a part of the circumpolar whirl. On the eastern coast, the climate is largely influenced by the conditions of the interior, because the wind comes from this direction; but the neighborhood of the ocean somewhat modifies the climate, and it is not so extreme as that of the interior.

As has been said, the interior climate is very extreme; and the cyclones and anticyclones which affect nearly the entire temperate belt, are much more marked than in other parts of the zone. The climate of the mountains resembles that of the region in which they are situated; but it is colder and usually more humid. Thus frost-covered mountains may rise from desert plateaus. Among the high mountains, much of the precipitation is in the form of snow. Between the mountains, and on the leeward side of them, arid and even desert conditions result from the fact that the winds are drained of their moisture in passing over the mountains.

This great variability in condition is strikingly shown in passing around the earth on one of the parallels of latitude, such, for instance, as that of 50° N., as described by Davis in his "Elementary Meteorology." Passing from the equable climate of the Atlantic, it crosses the European continent through regions so temperate that they are densely populated. In Asia, great plateau deserts are encountered, and on the Pacific coast the climate is quite severe; but in that ocean very equable conditions are found. The parallel enters British Columbia, where the climate is moderate and moist, passes over the high snow-covered mountains, and crosses

the great interior region of extreme cold, north of the Great Lakes, emerging across the Labrador peninsula to the Atlantic, in the middle of which the climate is modified by the warm Gulf Stream.

Arctic Climate.— The arctic climate is one of extreme and prolonged cold, and the ground is covered with snow for the greater part of the year. During the winter, the sun remains below the horizon, and in summer it does not set. On high mountains which rise into the cold layers of the upper air,¹ many of the conditions of the arctic climate extend into the temperate, and even into the tropical zones (Fig. 65). Between the tropics, a temperate climate is found at moderate elevations on the mountain sides.

Minor Variations.— Aside from the larger divisions of climate, there are many smaller ones. The climate may change very perceptibly even in a short distance, as, for instance, in going from the southern sunny side of a mountain to the shaded northern side (Fig. 68). Even a lake of moderate size may produce a perceptible influence upon climate; and it is not uncommon to find a belt adapted to fruit-raising whose boundaries include but a small area.

Changes in Climate.— There is an abundance of geological evidence to prove that there have been great changes in climate in parts of the earth's surface; and there is some reason for believing that there have been changes in climate within historical times. Recent studies in Europe seem to show that there is a period of slight variation in climate, extending over thirty-six years. The change is from drier and warmer, to cooler and moister conditions; and we are at present in the midst of the warm, dry part of the cycle.

¹ Of course, this applies only to the cold; for the position of the sun does not resemble that of the Arctic.

This is merely a suggestion, and cannot be accepted as a definitely established fact.

Of the geological evidence we are more certain. During the earlier ages of the earth's history, the climate of the globe seems to have been more moderate and uniform. Fossils of animals and plants that are at present confined to warm latitudes, are found preserved in rocks which are buried beneath perpetual snow. When these forms of life existed, this part of the earth must have been much warmer than now.

On the other hand, during one of the recent periods of geological history, arctic conditions extended down into temperate latitudes. The north temperate zone has just emerged from this period; and during its existence, sheets of ice, forming great continental glaciers, extended down into regions now densely populated. Northern Europe and northeastern United States were covered by these glaciers (see Chapter XVII.). At about the same time that this ice sheet extended over northeastern United States, the climate of parts of the Great Basin region of the West was transformed from an arid condition to one of relative humidity; and, during this time, great lakes existed where now there are only desert plains and salt lakes.

Perhaps the causes for these changes in climate are to be found in conditions which we do not as yet understand; but they may in part be due to variations in the movements of the earth about the sun. These are too difficult for simple statement; but they depend upon slow changes in the distance between the sun and earth, and upon the rotation of the earth's axis, known as the precession of the equinoxes.¹

¹ The teacher will find this theory fully stated in Croll's "Climate and Time," to which reference is made at the end of this chapter. A shorter, but very clear statement of the theory, will be found in Geikie's "Text-book of Geology," pp. 23-30.

Since climate varies so remarkably with differences in the elevation of land, or in the relation between land and water, it is possible that changes of a purely geographic nature may account for some of the variations. If large areas of land should be raised to greater elevations, or considerable tracts be lowered, or if the ocean currents should have their courses decidedly changed, the climate of parts of the earth would be very different from the present. Such changes actually have occurred, and in this way some of the climatic variations may be explained; but at present, only hypothesis can be offered to account for the change.



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Hann. — **HANDBUCH DER KLIMATOLOGIE.** Englehorn, Stuttgart, 1883. 8vo.

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Croll. — **CLIMATE AND TIME.** Stanford, London (Appleton & Co., New York agents). Fourth edition, 1890. 12mo. \$2.50.

A series of publications on the climate of the states and territories included within the arid belt of the West contains much valuable information. It is by Greely and Glassford, and was printed by the Signal Service at Washington.

There is an admirable discussion of some of the climatic features of New York, by Turner, in the "Fifth Annual Report of the New York Weather Bureau," 1894. This is distributed free of cost, and application for it should be made to the director, Professor E. A. Fuertes, Ithaca, New York.

¹ In most cases reference is not made to works published in languages other than the English; but these books are of especial importance. For a much fuller bibliography of the literature, reference may be made to the author's larger book, now in preparation. The present lists are intended to do no more than to refer to a few standard books in which reliable information may be found upon the several subjects which of necessity are very briefly treated in this book.

CHAPTER VIII.

GEOGRAPHIC DISTRIBUTION OF ANIMALS AND PLANTS.

General Statement. — There are three great zones occupied by life,—the air, the water, and the land. None of the animals of the air exist in that medium alone, but they are in part terrestrial or aqueous,—largely the former. Aerial animals belong to several groups of the animal kingdom, but for the most part are either birds or insects. On the land, nearly all the great groups are represented, though some of the truly aqueous animals are absent. In the ocean, the fishes and lower forms of animals are predominant, though there are groups of birds that dwell on the ocean for a greater part of the time; and some groups of mammals, such as the whales and seals, have adopted this zone for their home, although nearly all of their fellow-mammals live on the land. The group of reptiles is also represented in the sea, but the land is their main home. There is much difference between the life in fresh and salt water bodies, the main life characteristics being the same, but with many noticeable minor differences. For instance, insects are common inhabitants of the lakes and rivers, but are nearly absent from the sea; and the plant life of lakes is much more varied and high in type than that of the ocean, in which only a few species allied to the land plants are known to occur.

The Ocean.¹—The zones of air and land may be classed

¹ See also Chapter IX., pp. 168–174.

together ; but the ocean is so different that it must be considered separately. The mobility of the water, and the moderate temperature ranges over the greater part of the ocean, are both favorable to the widespread distribution of marine life ; and thus in great oceans we find some species ranging almost from one end to the other. The limit of temperature is the main check to the spread of ocean animals, and this is well illustrated by the distribution of reef-building corals, which are practically excluded from zones where the water temperature descends below 68°. Because the temperature of the ocean water descends as the depth increases, the forms of life change with the depth.

In the case of ocean plants, as indeed those of fresh-water bodies, depth is a very important factor in limiting distribution. Below a depth of 200 feet in the sea there is a practical absence of any form of vegetable life, because below this limit the sunlight is not powerful enough to perform the work which plants demand of it. The plants of the ocean are partly floating seaweed, so well illustrated in the gulf weed or sargassum, which drifts in the Gulf Stream, and accumulates in great areas, or Sargasso Seas, in the eddies within the whirl of the oceanic currents. Many of the plants are attached along the shore line, and the most favorable place for this is the rocky shore, which furnishes a firm base for attachment. Therefore, along rock-bound coasts, the area between tides is covered with a mat of seaweed (Figs. 89 and 204). Another favorable place for oceanic vegetation, is in quiet, partly enclosed arms of the sea, away from the reach of the waves. Here many forms of plants exist, some of them belonging to the true grasses ; and in such places these help to build level, swampy plains, known as salt marshes (Fig. 206).

Among the most striking features connected with the

oceanic life, are the wide distribution of its species and the great abundance of individuals. A striking difference is noticed between the animals existing in the warm waters of the tropical belt, and those occurring on the storm-beaten coasts of the cold temperate and arctic zones. The latter appear hardy, while the former are often exquisite in their beauty of color and delicacy of structure. There is much less difference in this respect among the inhabitants of the mid-ocean; for here the changes in physical conditions are less marked.

Fresh Water. — In fresh-water bodies there is much less variety of life, and usually there is not much opportunity for the study of distribution. Land animals, notably insects, often go to these water bodies for purposes of breeding; and in many cases marine fishes enter fresh water for the same purpose. In certain cases, owing to some accident, these ocean animals find their place of outlet cut off, and they become land-locked. As a result of this, we sometimes find true ocean fishes living in lakes. Sometimes fresh-water lakes become transformed to salt lakes, and this change gradually exterminates the animals. Finally, these water bodies may become *dead seas* in which practically no life exists, as is the case in the Great Salt Lake and the Dead Sea.

The way in which lakes become inhabited is mainly by the migration of life along the streams, or else by the entrance of land animals; and if a pond is made in the course of a stream, it will soon become stocked with both animal and plant life.

The Land. *Effect of Temperature and Moisture.* — On the land, one of the main factors determining distribution of life is that of temperature. As a result of this, we find very great differences between the faunas and floras of the tropics, and those of arctic latitudes. This difference affects both

variety and abundance ; for while there are many vicissitudes in the colder zones, everything favors the development of life near the tropics. The animals of the Arctic must prepare themselves for the long, cold winter, and at all times the conditions surrounding them are severe. Only a few forms of mammals exist there, and these are very hardy and well pro-



FIG. 68.

Near the timber line, Colorado.

tected with fur. Many of the mammals, and most of the birds, leave the coldest part of the zone during the winter; and some of the birds that spend the summer within the Arctic circle, in winter pass southward to the southern portion of the temperate zone. Reptiles are nearly absent from this cold region, and the few that do exist there are of small size. In summer, the land is clothed with vegetation up to the limits

of perpetual snow; but there is a very marked difference between the scanty flora of the Arctic and the luxuriant, almost impassable tropical forest. Within the Arctic, the trees are prevailing evergreens, and near the snow fields all trees disappear, while their place is taken by shrubs and the smaller forms of plant life.

Intermediate conditions exist within the temperate belt.



FIG. 67.

Above the snow line, Mt. St. Elias, Alaska.

There is a great variety of plant and animal life, in the southern part merging into the tropical conditions, in the northern portion assuming arctic characteristics. Many of the birds of the colder parts of the zone migrate to the south in the winter; but the insects, reptiles, and many of the mammals, spend a part of the winter in a torpid or dormant condition, in this respect resembling the winter behavior of plants. They have adapted themselves to the annual

climatic change from the rigorous winter to the warm summer.

The influence of temperature upon the abundance and kind of life, is also illustrated in the ascent of mountains (Fig. 66). Within the tropics, one may pass upward into places where plants exist, which in many respects resemble those of the temperate zone; and in this zone a flora of arctic habit exists upon many of the highest mountain tops. In studying the distribution of animals and plants, altitude is found to be a very important factor; and as one ascends

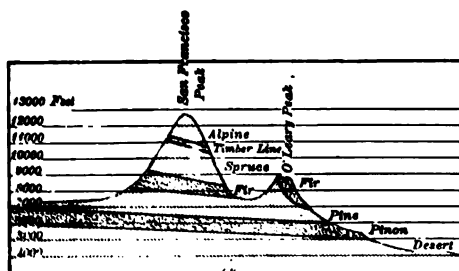


FIG. 68.

Effect of sunlight in raising the zone of vegetation higher on the southwest than the northeast side of a mountain.

the limit of plant life is practically found, although in favored places some few species may extend even above this line. Before the snow line is reached, one passes the timber line, and goes from the forest-covered slope to one on which trees do not grow (Fig. 66). The elevation at which this is reached, varies with the latitude (see Fig. 65), and even with the portion of the mountain. If one side is exposed to cold winds, the limit is reached at a lower altitude than on the opposite side; and the same is true of the side of the mountain which receives the least sunlight, for in such places the average temperature is lower than on the sunny side (Fig. 68).

a mountain range, he finds familiar plants and animals disappearing one by one, and their place only partly taken by species which rapidly decrease in number as the ascent continues. When the snow line is approached (Fig. 67),

The moistness of the climate also affects the spread of animals and plants; and in absolute deserts we find an almost entire absence of life, while in those arid regions which are not true deserts, the plant and animal life are peculiar, for the conditions are very unfavorable (Figs. 69 and 70). Reptiles and a few insects, mammals, and birds constitute the fauna; and the flora is characterized by stunted, spiny bushes, and a brown grass that becomes transformed to hay as it grows in the dry atmosphere. Here the cactus thrives, and other prickly and unusual forms of vegetation exist. With abundant moisture, vegetable and animal life flourish, and this is one of the reasons for the luxuriance of the tropical forests; and with abundant plant growth, animal life also becomes abundant. How



FIG. 69.

Arid land vegetation.

marked this effect is, can readily be understood by considering the difference between the sandy wastes of the Sahara (or the arid regions shown in Figs. 69 and 70) and the tropical forests in the same latitudes (Fig. 71). While these are extremes, even slight differences in rainfall will cause marked changes in life.

Plant and Animal Habits. — Aside from those differences among animals and plants upon which the zoölogical and botanical classifications are based, there are certain differences in habit which are of some interest from the present standpoint. Plants are for the most part fixed in a definite place, and the opportunity of distribution comes only from

the seeds. Therefore in the study of geographic distribution of plants, the seeds are of much interest. Some are heavy, and these drop to the ground close by the tree; but in some cases, these heavy seeds are enveloped in a fruit, which is eaten together with the seed; and since the germ is often protected by an indigestible shell, the vital part of these seeds may be carried for long distances, and then be left upon the ground unharmed. Some seeds cling to the



FIG. 70.

Arid land vegetation in the Cañon of the Rio Grande, northern New Mexico.

fur of animals and are thus distributed, and many are drifted to distant regions by the winds. In these, and other ways, plants are spread from one place to another.

Among land animals, there are great differences in habit. Some move slowly, others rapidly, and some are able to fly in the air. Most animals of the land dwell on the surface; but for a part of the time, many make their home either in the air or in the water, and some spend a part or all of

their time beneath the surface of the ground. Naturally, because of these variations, there is much difference in the distribution of animals, and in the means by which they are distributed.

Life Zones. — As a complex result of these animal and plant peculiarities, together with their physical surroundings, and certain inherent conditions which cause life to grow and develop, there has resulted a peculiar distribu-



FIG. 71.

The tropical forest.

tion of life on the land. The most perfect adjustment to conditions is noticed upon the connected continents; and here we find three great zones, the tropical, temperate, and arctic, in each of which there are sub-zones which are due to irregularities in climate or in topography (Fig. 72). There are mountain and desert irregularities, as well as others.

Not only do these zones exist upon the several continents, but quite different species, both of animals and plants, characterize the separate continental areas. The plants and ani-

mals of Europe are quite different from those of America; of South America from Africa.¹ Yet there is remarkable uniformity in the fact that the same large groups are present in each, as if by some means there had been an occasional connection or communication. Evolution teaches us that animals and plants have been developing from simpler

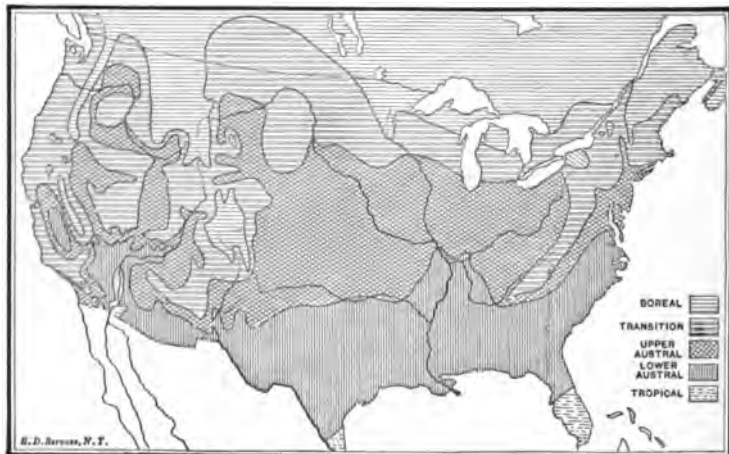


FIG. 72.

Diagrammatic representation of the life zones of the United States, showing influence of latitude and topography.

to higher forms, and we now know considerable concerning the steps along which this has proceeded. The fact of the difference between the life of the several continents, shows that there has not been *constant* connection; but the resemblances prove that there has been *some* communication.

¹ To illustrate, we have temperate and tropical zones in both South America and Africa, and in each of these also the subdivisions of coast, desert, and mountain belts. But the tropical forest of Africa bears only a general resemblance to that of South America. However, these resemble each other much more closely than do the forests of tropical and arctic zones.

Even more strikingly is this proven by the resemblances and differences between the life of the oceanic islands and that of the continents. These land bodies are separated, and in some cases have always been separated, by a great ocean barrier; yet at times, as for instance in the Bermudas and the West Indies, the life of the islands resembles that of the neighboring mainland, although numerous species are absent. On the other hand, there are many cases in which the insular life is entirely unlike that of the mainland. For instance, the only native mammals of New Zealand, are two species of bat, which have been able to spread themselves by means of flight. Other vertebrate animals are scarce on this land, and in most cases the animals are of peculiar types.

The animals of the East Indies are quite like those of Asia; but Australia, which lies only a short distance south of these, forms a perfectly unique life zone. Excepting a few species of bats, rats, and mice, all of the mammals belong to peculiar types, such as the kangaroo group, and the group to which the duck-bill belongs, — an animal which combines the habits and characteristics of mammals with that of laying eggs. The birds are also peculiar, including among their number many king-fishers, parrots, birds of paradise, and other peculiar forms.

The Spread of Life. — The prime cause for the wide distribution of land animals is found in themselves, as a result of voluntary movement from one place to another. Many birds may easily pass for long distances, and in this way they may reach far-distant lands; but usually they are content to stay in their normal home.

During storms they may be blown far from their home, and when they alight, it may be upon some distant island, or in some other place from which return is not easy. Ships a hundred miles from shore, often serve as a resting place for

some land bird which is lost on the open sea. In the water there are floating logs which may serve as resting places, and in this way flying animals may be distributed. A few years ago, during a violent storm, a sea gull fell exhausted not far from Ithaca, New York, at a distance of two or three hundred miles from its ocean home, which was certainly not north of Philadelphia. Naturally, because of this aid of the wind, winged animals are most widely distributed.

Land animals that cannot fly, distribute themselves by moving over the land, each generation pushing its frontier line farther than the preceding, provided other conditions are favorable. As is stated in the next section, there are certain limitations to this natural spread of life.

In a second way, land animals may be distributed by accidental means. Drifting in the ocean currents, there are often logs of wood which have floated down some river to the sea. Tree trunks from the American coast are in this way borne to the European coast and there stranded. Animals may be carried upon these, and if they survive the journey, they may begin to increase on some land remote from their old home. This is particularly likely to happen to animals like reptiles, which can live for a long time without water or food, or to insects which are in the egg or in the cocoon. In rare cases, even the higher types of life may pass through such a journey; but such animals must be small, for only these can be thus floated. It is for these reasons that the large mammals are so rarely found upon the islands of the ocean, even though the distance to the mainland is slight.

By a change in climate, such as that which produced the glacial period, animals may be forced to migrate, and in so doing they may cause other animals to abandon their homes. When the ice enveloped the northeastern United States, the

animals were either killed or driven away into the southern and more favorable regions. The effect of this migration must have been felt far from the ice front; and there are still signs of its influence in the distribution of animals and plants in eastern United States.

Barriers to the Spread of Life. — The great barrier is the ocean. More effectually than any other feature of the earth it serves as a check to the spread of animals and plants. In the case of Australia, it has served as an effectual check upon the spread of the large and powerful animals of the East Indies, and in a less perfect way, even upon the more easily distributed forms of life. Short arms of the sea are not so effectual, but even these serve as a partial barrier. The study of the problem offered by the Australian fauna, leads to the conclusion that this continent has not been connected with the Asiatic lands since the higher animals began to exist; and in other parts of the world, a study of the distribution of life, proves that some of the ocean barriers of the present have not always existed.

Next to this great oceanic barrier, the most important obstacle to the spread of life is probably to be found in high mountain chains, such as the Andes and the Rockies. Many animals and plants are completely checked by these. Nearly the same is true of deserts; for if it is not possible to pass around these, many species find it impossible to pass from one side of them to the other. In some cases even large rivers serve as a boundary line, separating a zone occupied by a species from one in which it is absent.

Effect of Man. — The above remarks hold only for the natural distribution. Now man has come upon the scene as a disturber of the natural order, and everywhere in the world we see the result of his interference. We have European and Asiatic trees in the garden, and, in some places,

even in the forests. There are foreign weeds in the field, foreign birds, insects, and mammals (notably the rat), as pests, or as unnoticed additions to the flora or fauna. The ancient marsupials are no longer the most important mammalian possessors of the Australian zone, but man has caused an invasion of their territory.

Man is killing here and adding there, with the result that intentionally or unintentionally, he is changing the life zones; but while thus interfering with the natural spread of life, and, in some cases, succeeding in domesticating plants and animals of one zone to the conditions of another, he is not able to disturb the great divisions of tropical, temperate, and arctic, of mountain and desert. These depend upon physical conditions of too fundamental importance. The camel may be domesticated in the desert of southern California, but it cannot thrive in New England; the tiger might be introduced into South America, but not into Scandinavia; the palm of the central Pacific might be made to grow on the islands of the central Atlantic, but not on the slopes of the Rocky Mountains. Thus while man will greatly aid in the distribution of animals and plants, in general he will succeed only in disseminating them over zones in which the prevailing conditions are similar.



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PART II.

THE OCEAN.

CHAPTER IX.

FORM AND GENERAL CHARACTERISTICS OF THE OCEAN.

Distribution of Land and Water.—A glance at a globe shows a very marked irregularity in the distribution of land and water in the different hemispheres. It is possible to divide the earth into two hemispheres, in one of which there is little land, while in the other the water area is small (Fig. 2). Nearly three-fourths of the earth's surface is covered by water, the total area of water surface being about 145,000,000 square miles. Land rises from the water in the form of continents and islands, which differ greatly in outline and topography.

Composition of Ocean Water.—The ocean is between 96 and 97 per cent pure water, the remainder being divided between several salts, of which the most abundant is common salt. In addition to this common salt, there is an appreciable amount of chloride of magnesium, carbonate of lime, some sulphates, and very minute quantities of other substances. Probably some compound of every known element is dissolved in the ocean, in such minute quantities that they can be detected only by the most careful analysis. In addition to these slight impurities, the water has absorbed a considerable amount of atmospheric gases. It is upon this that the ocean life depends.

In different parts of the world, there is a considerable variation in the percentage of salt impurities, the range being between 3.3 and 3.73 per cent. At the same time

with this change in amount of salt, there is a variation in the density of the water. Representing fresh water as 1, the *average density* of sea water is 1.026. There are many reasons for variation in the salinity of sea water. Where rivers enter the ocean, the density is decreased by the addition of fresh water; and also where rains are abundant, as they are in the belt of doldrums, the surface water has its density decreased. On the other hand, where evaporation is great, the removal of the fresh water tends to concentrate salts and therefore to increase the density. In the Mediterranean and the Red Sea, the ocean water is relatively dense; and the same is true of the belts of ocean water over which the dry trade winds constantly blow.

Color and Phosphorescence. — The color of the ocean is naturally blue. This is partly due to the fact that the blueness of the sky is reflected upon the water surface, and partly to the scattering of light rays which enter the water, this cause being analogous to that of the blue color of the sky itself. The color of the bottom often imparts to the water a different shade from the typical blue of the ocean; and where the water is shallow, green shades are often produced. The Red Sea owes its color to the presence of many minute forms of vegetation, belonging to the group of Algæ, while the color of the water near some coasts is due to the presence of great quantities of mud brought down by the river.

At times, particularly on quiet nights, the ocean waters are aglow with a silvery gleam of light, which is known as *phosphorescence*. It is similar in origin to the glow of the fire-fly which we see on warm summer nights. In the surface waters of the ocean, there are countless millions of microscopic animals, nearly all of which are able to emit a tiny spark of this strange light; and their power to do this seems to vary from time to time. Therefore on some

nights the surface is free from this light, while at other times every ripple causes a silvery gleam. In rowing upon the surface of the sea at such times, a trail of light follows behind the boat, and drops of gleaming water fall from the tips of the oars.

Exploration of the Ocean Bottom.—It is only recently that the bottom of the ocean has attracted much attention. Until thirty years ago, it was supposed that after passing below a depth of a few hundred feet, the bottom of the ocean was a great, uninteresting desert. And thus, until that time, we were almost entirely ignorant of the conditions existing on more than one-half of the earth's surface. To the naturalists of the time it seemed absolutely impossible that life could exist in the depths of the sea.

When oceanic cables were laid, the beginning of the study of the deep sea was made, and proof was soon obtained that animals did live in the great ocean depths. This proof first came from the Mediterranean, where a submarine cable was drawn to the surface for repair. Attached to it were a number of animals, which therefore must have lived where the cable lay; and the depth of water at this place was much greater than the supposed limit of life. The fact that conditions favoring the development of animals probably existed over the entire ocean bottom, immediately created a desire for exploration; and to this scientific interest was added the practical one, which resulted from the necessity of obtaining a knowledge of the physical features of the bottom, in order to make more easy the extension of oceanic cables; and soon governments began the study of the ocean bottom.

Methods Used in Deep-sea Explorations: *Sounding.*—In a study of the ocean bottom, we wish to discover something concerning the life that exists there, something about the

topography, and something concerning the kind of bottom, as well as the character of the water, and the various physical conditions. For this purpose, one thing is of prime importance, namely the depth; and in every deep-sea exploration this is the first fact obtained.¹ For this *sounding*, many ingenious contrivances have been invented, the one best

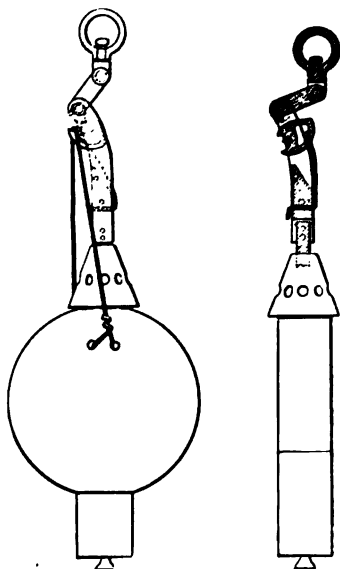


FIG. 73.

Deep-sea sounding machine, with and without the sinker.

adapted to deep-sea work being the Sigsbee deep-sea sounding machine (Fig. 73). A weight attached to the end of a fine steel wire, is carefully lowered until the bottom is reached. The ball of the sounding machine sinks by its own weight; and when it touches bottom a jar is sent through the wire, which is felt even at the surface. The entire machine is very delicately constructed, and it records ocean depths with great accuracy. The wire used is so fine that it would be impossible to draw the weight back to the surface, and the instrument is so contrived that this is left behind when

it touches the bottom of the ocean (see Fig. 73).

The weight is nothing but a cannon ball through which a hole had been bored. Into this hole is placed a cylinder, which remains open during the passage of the weight to the bottom, and which is automatically closed when the line is drawn in. Usually the bottom of the cylinder is covered

¹ Ocean depths are measured in fathoms, a fathom being six feet.

with wax or soap, to which clings a sample of the mud of the ocean floor; so that as the instrument is drawn to the surface, we have both water and mud from the bottom.

Near the weight a thermometer is attached to the line; and this is so made that it is inverted when the wire is reeled in, and an automatic register of the temperature at the time of inversion is thus made. Very often several thermometers are attached to the line at different distances, so that we obtain a knowledge of the temperature of the ocean water from the surface down to the very base of the column.

Dredging. — In order to obtain a knowledge of the kind of life that exists in these great ocean depths, another method, that of dredging, must be followed. The dredge, or deep-sea trawl (Fig. 74), is an iron frame several feet in length, to which is attached a bag net. This is lowered to the bottom and dragged over it, usually for several hours. The sounding apparatus is lowered perpendicularly; but the dredge is lowered to the bottom, and then more rope is reeled out, so that it may be kept upon the bottom and dragged over it. This is done partly by attaching weights to the dredge, and partly by the natural sagging of the wire rope. After the dredge has been down for a



FIG. 74.
Deep-sea trawl.

sufficient length of time, it is drawn to the surface and its contents examined.

Imagine a balloon sailing through the air at a height of three miles or more, and dragging a frame a few feet in length, over a distance of a few miles. If the operators of this apparatus should imagine that, as a result of a few trials, they had obtained a fair knowledge of the life existing on the surface of the earth, it will readily be seen that they would be very much mistaken. All swiftly moving animals would escape, and only those would be taken which were small enough to enter the dredge, and so slow that they could not escape from it. In a measure this is true of our explorations of the deep sea. If large animals exist there, our methods of exploration are not calculated to discover

them, nor should we expect to obtain many animals that are capable of rapid movement.

Topography of the Ocean Bottom : General. — There is a very profound difference between the outline of the ocean bottom and the features of land, as we know them on the continents. In both

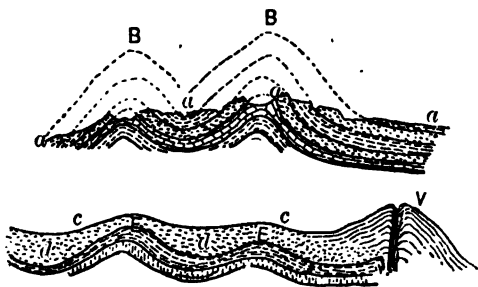


FIG. 75.

Diagram contrasting land and ocean bottom topography. *a, a, a*, land surface; *B, B*, height to which mountain would rise if denudation were not acting; *c, c*, undulating ocean bottom; *d, d*, ocean sediment partly obscuring mountain fold *E, E*; *V*, volcanic cone.

places the crust of the earth is subjected to a tendency to wrinkle, and therefore to form mountain folds; and in both cases also, volcanoes are produced. But on the land, there are forces at work which are absent from

the ocean. The rain, rivers, changes in temperature, and wind, are engaged in the combined action of carving and sculpturing the land, the result of which is to make the surface very irregular, and at the same time to gradually lower it (*a, a*, Fig. 75). None of these tendencies exist in the ocean.

The oceanic areas are the gathering grounds for the waste of the land. Materials worn from the continents are borne to the sea in rivers, or are wrested from the land margin by waves, and distributed over the sea bottom. Materials carried in solution by river waters also find their way to the ocean; and from these the animals that dwell in the sea, are able to take the materials which they build into their skeletons, and which upon death they leave as a contribution to the ocean floor. Therefore the tendency of deposition in the ocean is to smooth the surface. Thus in the sea, while excessive elevations are occasionally found, the general topography is remarkably uniform. There are great elevations, because nothing is present which tends to destroy the diversities produced; but the absence of the agents that are carving and sculpturing the land, makes the sea bottom a place of great regularity.

In the ocean, there are prevailing conditions of great, wide-stretching oceanic plains or plateaus; and where there are elevations, these are usually so gentle that they would appear to be nearly level. Occasionally, where volcanic peaks rise in the ocean, we find exceptionally steep slopes. The agents of the air are not present to carry away the materials which are building the cone, and therefore most of the material that is ejected is piled into one mass.

In a distance of about 70 miles from Porto Rico, the depth of the ocean descends to 4561 fathoms; and in this region there is a difference in elevation of fully 30,000 feet in a

distance of about 80 miles. Within sight of the Bermudas, at a distance of from 10 to 30 miles from land, the ocean reaches a depth of from 2700 to 2900 fathoms. Among the oceanic islands of the Pacific, differences in elevation fully as great as these are frequently discovered. On the land there are no such *excessive* differences in elevation as those which exist among the volcanic islands of the ocean.

The Atlantic Ocean.—Perhaps the best way to obtain an idea of the topography of the Atlantic Ocean, is to make a section across it, following approximately the line traversed by the oceanic steamers (Fig. 76). Starting from the shore of New York, an even, gently sloping plain is found stretching eastward to a distance of from 50 to 75 miles. It is almost level, and its features are quite like some of the very level plains on the land. This plain extends far above the mouth of the St. Lawrence, including nearly all of the area between the present New England coast and a line about 100 miles from the shore. South of New York this submarine plain, or *continental shelf*, rapidly narrows until off the Carolina coast it is a very narrow strip. Such a continental shelf as this, is found along the border of nearly every continent on the earth, though in width there is much variability (Plate 14).

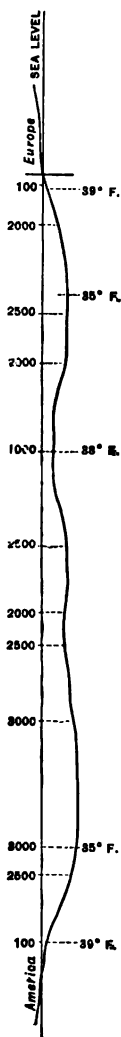


FIG. 76.
Cross section of Atlantic on the 40th parallel, showing depths in fathoms and the temperature. Vertical greatly exaggerated.

Passing eastward, and for a while leaving the track of the ocean steamers to the northward, a region of very rapid slope is encountered. This is known as the *continental slope*, and in many places the rate of its descent is as great as that of a mountain. In a distance of a few miles, one passes from the edge of the shelf, whose depth is usually about 100 fathoms, to oceanic depths as great as 1000 fathoms. After the 1000-fathom line is reached, the *excessive* rapidity of the slope decreases; but still the ocean depth rapidly increases to 1500 or 2000 fathoms. In a distance of from 50 to 100 miles, the depth has increased from 100 to 2000 fathoms, where the true oceanic plateau is reached.

Almost the entire ocean is included in this deep plateau area. Extending northward and southward, to the Arctic and the Antarctic circles, there is a monotonous, level plain, with ocean depths varying between 1000 and 3000 fathoms, and only rarely broken by some slight interruption.

Passing eastward, this plateau extends just beyond the middle portion of the ocean, where the bottom gradually begins to rise, forming the *Mid-Atlantic Ridge*. It extends with considerable uniformity from Iceland to the southern limit of the Atlantic Ocean; but it reaches the surface only here and there, as in Iceland, the Azores, St. Paul, Ascension, and Tristan da Cunha. It is not a continuous ridge, but an elevated portion of the ocean bottom, whose broad crest now reaches the surface, and again is fully 1000 fathoms below it. Almost everywhere along this area, the ocean depth is less than in other places far from land.

After passing the crest of this rise the depth again increases, until soundings of over 2000 fathoms indicate another approach to the great submarine plateau. The plateau on the eastern side is less extensive than that on the western; and as the European coast is approached, the deep

oceanic plateau rises toward the continent. Here the conditions that were noticed off the American shore are practically repeated. There is a slope and then a continental shelf, which merges into the continent itself. In the vicinity of the British Isles the shelf is broader than it is along the coasts of France and Spain.

Other Oceans.—Much less is known concerning the conditions in the depths of the Pacific; and almost nothing is known concerning the Arctic and Antarctic oceans. So far as our knowledge of the Pacific and Indian oceans warrants any definite conclusions, we may say that the conditions of the Atlantic are in a general way repeated. The great monotonous plain is more broken by volcanic peaks; and a greater depth is found in the Pacific than in any other part of the ocean (see Plate 14). Depths greater than 4000 fathoms have been discovered in several places; and in one place, near the Kurile Islands, a sounding of 4655 fathoms was made. The deepest place in the Atlantic (4561 fathoms) is near Porto Rico. It is a noticeable fact that these excessive depths are found close to the land. While the greatest elevations occur on the land, the average oceanic depth is very much in excess of the average land elevation¹; and the great land elevations are at a considerable distance from the sea, so that the elevation of the high mountain peak above its base is much less than its elevation above sea level. The greatest ocean depths descend almost directly from the land.

Topography near the Coast.—While this description of the ocean bottom will serve to present the features of the deep sea, it does not convey any idea concerning the irregularities near the coasts. Along all continent margins, and particularly among archipelagoes, the form of the bottom is

¹ The average depth of the ocean is as much as 12,000 feet, while the average elevation of the land above sea level is not much more than 2000 feet.

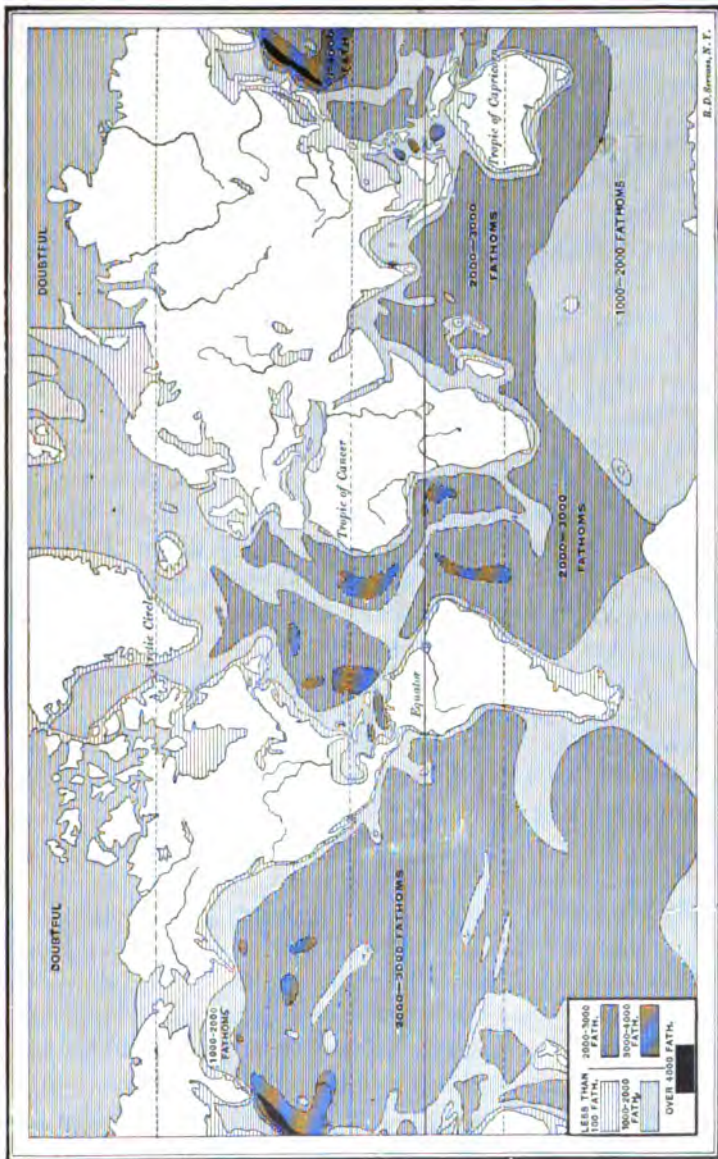


PLATE 14.

Sketch map showing the approximate depth of the ocean.

exceedingly irregular. Without entering into the subject in very great detail, these irregularities could not be adequately described; and indeed, our knowledge of the larger part of the ocean floor is so slight, that as yet we know only the general features.

— **Temperature of the Ocean Bottom.**— In the neighborhood of continents, where the depths of the sea are relatively slight, the temperature is more or less irregular, and determined by local conditions. It changes with the season, and is influenced by the oceanic and tidal currents, and even by the prevailing winds.

After passing this shallow and variable zone, very uniform temperature conditions are encountered. As a general statement, it may be said that throughout the ocean, there is a decrease in temperature with the increasing depth. Starting from the variable zone of relatively high temperatures, there is at first a rather rapid descent until the zone of about 40° is reached at a depth of a few hundred fathoms. After this, there is a very gradual descent in temperature (Figs. 76 and 83), until the cold becomes as great as that of fresh water at the point of freezing. Over a very large part of the ocean bottom the temperatures are between 32° and 35° . On some parts of the ocean bottom, particularly in the South Atlantic and the South Pacific, temperatures of 32° and even of 31° are found.¹

While this is true as a general statement, there are numerous exceptions to it. In the Mediterranean (Fig. 77), there is a decrease until the level of the bottom of the Straits of Gibraltar is reached, after which the temperature remains uniform, while in the Atlantic there is a normal decrease.

¹ In this connection it must be remembered that the freezing-point of salt water is lower than that of fresh water; and therefore temperatures lower than that which we call the freezing-point may be found in the ocean.

This is because the Mediterranean is enclosed, and its water enters over the Straits, and hence with the temperature at that level. Also, in the Gulf of Mexico, the temperature in the deepest part is only $39\frac{1}{2}^{\circ}$, which is the same as that at the Straits of Yucatan. The deep part of the Gulf of Mexico is 2119 fathoms, while that of the Straits of Yucatan is only 1127 fathoms. It will be seen, therefore, that this decrease in temperature does not *depend* upon increase in depth.

The peculiar distribution of temperature in the deep sea, is probably due to movements of water on the bottom. In the Arctic regions the cold water sinks, while at the tropics warm water rises; and there is a constant passage of water from one of these zones to the other, giving a surface movement toward the poles, and

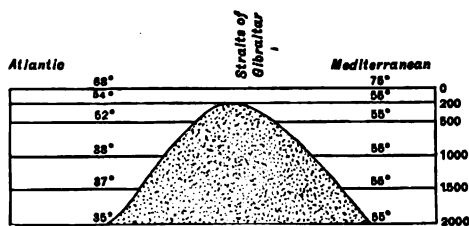


FIG. 77.

Diagram showing the temperature peculiarities of the Mediterranean.

a bottom movement toward the equator. If a barrier exists in the line of this deep-sea circulation, the normal decrease in temperatures is interfered with. At the Straits of Gibraltar, the water which passes into the Mediterranean does not come from the *bottom* of the ocean, but from a level determined by the bottom of the Straits.

Light on the Ocean Bottom. — It seems certain that sunlight cannot possibly penetrate through several miles of salt water; and if this is true, the greatest depths of the ocean are practically dark, so far as sunlight is concerned. Although it is probable that no sunlight penetrates to these

zones, it still seems certain that some kind of light does exist there. This conclusion is forced upon us by the fact that many of the animals in the depths of the sea have well-developed eyes; and, further, that many of them are brilliantly colored. Animals living in dark caves become blind; and it seems hardly probable that these inhabitants of the deep sea would continue to develop eyes for ages after their usefulness had ceased.

Phosphorescence is a possible source of light on the ocean floor. After nightfall, whenever a dredge-load of materials is brought from the deep sea to the surface, it is aglow with the dull white light of phosphorescence. Each animal, each particle of mud, gleams with this light.

Materials composing the Ocean Floor: *Mechanical Sediments*. — There are two classes of substances spread over the ocean bottom: one mainly derived from the land, or from fragments of rock emitted from volcanoes; the other, from animals which have lived in the ocean. The latter covers by far the greater part of the ocean floor. The sandy and clayey fragments of rock which are derived from the land, are spread over the bottom of the sea only in the neighborhood of the coasts.

***Globigerina Ooze*.** — One of the most striking facts connected with the ocean, is that the floor, covering an area greater than one-half that of the entire earth's surface, is made up of the remains of minute animals. When seen with the unaided eye, the deposit is a blue mud or ooze; but when examined with the microscope, it is found to be composed of fragments or entire shells of tiny animals, generally belonging to the group of Foraminifera. The most abundant of these are members of the genus *Globigerina*; and these are so characteristic of the deposit, that it is known as the *Globigerina ooze* (Fig. 78).

It covers the greater portion of the Atlantic, and large parts of the Pacific and Indian oceans. Its rate of accumulation must be extremely slow ; for although the animals which compose it are very abundant in the surface waters of the ocean, they are so small that it must require long periods of time to form any considerable depth of ooze. Each particle must depend upon the life and death of a tiny animal. The chalk of England, and other regions, is a rock whose origin was similar to that of the *Globigerina* ooze.

Red Clay.—At a depth greater than 2000 or 2500 fathoms, the bottom ooze changes its character and becomes known as red clay. This form of ocean deposit is particularly abundant in the Pacific, although it is not entirely absent from the Atlantic. It is one of the most remarkable deposits being made in the ocean. In these great ocean depths, the power of the salt water to dissolve the lime of shells has increased until this substance is taken in solution as the shells drop from the surface. Therefore the insoluble portions, of which there are tiny amounts in every shell, are the only parts of the *Globigerina* that reach the bottom. Therefore the ooze is in part a residue of the shell after the soluble portions have been removed. And if the shells were small at the beginning, how much smaller must these tiny remnants be!



FIG. 78.
Globigerina ooze from the ocean bottom.

It is not exclusively made of the residue of the shells of surface animals, but contains contributions from other sources. The most common addition comes from pumice rocks, which were ejected from volcanoes, and after floating for some time settled to the ocean bottom at some distant point. Therefore, remnants of volcanic ash or pumice are common in the red ooze. Aside from this, there are fragments of meteorites which have dropped to the bottom, indicating exceedingly slow accumulation. This deposit covers an area of over 51,000,000 square miles, which is a little more than that covered by the Globigerina ooze. Each kind of deposit covers an area equal to about one-fourth of the earth's surface.

Life in the Ocean: Pelagic or Surface Faunas.—The ocean is the great meeting ground of the life of three provinces,—the air, the land, and the water. Forms belonging to all the great groups of the animal kingdom find it possible to live in the conditions which exist in the ocean. There the conditions of life are remarkably uniform; for there are few changes in temperature, and few variations such as animals on the land experience. Day after day, and year after year, the surrounding conditions are nearly the same. No such difference exists between the surface faunas of the ocean in different latitudes, as between the land animals of the tropics and the temperate latitudes. This is partly because the temperature of the water changes very slowly and very slightly, and it is also in part due to the fact that the waters of the ocean surface are in movement, so that the temperatures of one latitude are distributed to another. From the tropics, the currents bear bodies of warm water, and in them animals of tropical origin; and these may be distributed far over the surface of the ocean.

So uniform are the conditions of temperature, that even

very slight differences will cause marked changes in the faunas. In the Gulf Stream, which flows at a distance of 100 miles or more from the land, there are found many creatures of tropical origin, which cannot exist in the colder waters near the coast. At times, during strong prevailing winds from the south, these creatures are driven into the colder waters; and, as a rule, they are unable to survive the change. The ocean surface is particularly favorable to the wide distribution of animals. It is constantly in motion, and as a result of this, hardy animals may be distributed from one end of an ocean to the other.

Many of the oceanic animals are free-swimming creatures, others are drifting animals, and still others are attached to floating objects. This last group is particularly liable to be found attached to the floating seaweed or Sargassum, which at times, particularly in the eddies between the ocean currents, exists in such abundance that these areas are known as sargasso seas. All except the largest of the surface animals are in a measure at the mercy of the winds or currents.

At the surface, and on the ocean bottom, there is abundant life. Between the surface and the bottom, over the greater part of the ocean, there is a zone of water, at least two miles in depth, whose conditions as regards habitation are not known. It is the greatest unexplored area on the earth, and we are unable to say whether it is a great desert region, or whether it is actually inhabited. It is exceedingly difficult of exploration; but since animals have been found in every explored nook of the ocean, and have become adapted to each place, it seems probable that some have found this zone and have adapted themselves to it.

Littoral or Shore Faunas. — Along the shore line, the conditions more closely resemble those of the land than in any

other part of the ocean. There is no such monotony of conditions as we find at the surface of the ocean away from the land. But from day to day, from season to season, and from place to place, there are very marked differences in the conditions upon which the animals depend for their existence and variety. Here, as in every part of the ocean, temperature is a very important cause for differences in faunas and for variation in animal forms. Even a few degrees of temperature will cause a very marked difference in the



FIG. 79.

Coral reef on the Australian coast.

abundance and variety of animal life. This is well illustrated on the coast of Massachusetts, where the end of Cape Cod serves as a dividing line between two quite distinct faunas, because on the northern side of the cape the water is

cool, while on the southern side it is comparatively warm. The influence of the Gulf Stream is felt south of Cape Cod, while north of it, in Massachusetts Bay, the cold Labrador current reduces the temperature.

Another limitation upon the spread of animals along the shore, is that of food supply. Perhaps the best illustration of this is found in coral regions. At the points reached by food-bringing currents, the abundance and variety of life is

very great (Figs. 79 and 207), and the coral polyps select from the water the food that they need. Soon the waters are robbed of their food supply, and in passing on are unable to support abundant coral growth. It has been noticed among the coral reefs, that on one side of a coral bar, the polyps grow readily and in great numbers, while on the opposite side, they are very scarce and not well developed. In the one case there is an abundance of food, in the other, the food supply has been taken from the water by those corals which have the more favorable situation.

It follows from this that circulation of water must take place in order to bring fresh food supply to the animals which are fixed in one place, and which are not able to move about for the purpose of obtaining the food which they need for existence. Therefore we rarely find coral reefs in other places than those bathed by currents.

The animals that dwell upon the shore line are of several kinds: those that are free swimming and able to move about; those that are drifted against the shore by accident; those that crawl about; those that are attached firmly to the rocky coasts; and those that burrow in the clay and sand which are found in certain places. Since animals that are in the habit of attaching themselves permanently to one place, can find no opportunity for this attachment in places where sand and clay form the coast line, it follows that as a result of the differences in kind of rock, there may be very marked changes in the faunas from one place to another. On the rocky coast, the animals are almost entirely of types which are attached or which crawl about, while on shores that are sandy or clayey, the animals are almost all of the burrowing and crawling types.

Faunas of the Ocean Bottom.—Every dredge load that is brought to the surface during deep-sea exploration, proves

the presence of a great pressure of water in the depths of the sea. The more highly organized animals, such as the true fishes, are unable to accommodate themselves to this change in condition; and when they are drawn to the surface, they are commonly broken by the expansion of the gases within the body. Their eyes protrude from the head, the air bladder extends from the mouth, and the skin is cracked and fissured. Thus while they may live with immense pressures upon every particle of the body, they are unable to exist when the pressure is removed from the outside, while it still partly remains on the inside.

As a result of deep-sea exploration, it has been found that all the ordinary types of marine animals exist on the ocean bottom, and that in certain favorable places they exist in great variety and abundance. Fishes of types not unlike those found at the surface, swim about in the depths of the sea; starfishes, crabs, and shrimp, crawl over the bottom ooze; shells not unlike those which we find along the sea-shore, live on the bottom or burrow into it; and some forms exist attached to solid parts of the bottom, while others are permanently attached by means of root-like extensions of the body, which ramify through the mud. Among the animals of the ocean bottom, are found certain types that in an earlier stage in the history of the earth were quite abundant, but which do not now exist elsewhere,—as if they had retreated to this place as an asylum where changes and struggles are practically absent.

As in other portions of the ocean, temperature is the main cause for variations in the kind of animals dwelling on the sea floor. A change of one or two degrees causes an almost absolute change in the faunas. This is in large part because of the unvarying conditions of the ocean bottom. There is no effect of day and night, nor of season; but year after year,

and age after age, the conditions of temperature remain the same. Therefore animals which have become accustomed to a practically permanent condition of 35° , will find a decrease in temperature to 33° so great that they cannot survive the change.

Since these deep-sea animals live amid conditions of unvarying temperature, there is naturally a very great decrease in vitality as the temperature decreases. And with permanent temperature conditions of 32° (or as in some cases even of 31°), the possibility for the existence of life becomes very much decreased. Therefore in the coldest zones of the ocean, the abundance of animals is not great.

Another feature upon which the life of the ocean bottom depends, is that of food supply. So far as we are able to judge, the animals of the ocean bottom exist partly upon one another, but mainly and ultimately upon a supply of food that rains down upon them from above. The death of the animals of the surface constantly supplies the bottom creatures with the necessary food. As it sinks, each tiny *Globigerina* serves as a morsel for some animal of the ocean bottom; and the lack of abundance of this kind of food supply, seems to place a limitation upon the excessive development of animals on the ocean floor. This is probably one of the reasons why the variety and abundance of the bottom animals is not greater. There is not food enough for many more to exist.

The animals of the ocean depend upon a supply of oxygen for breathing; and this is as true of the animals of the ocean bottom as it is of those at the surface. It is not difficult to understand how the creatures that dwell in the surface waters are able to obtain their supply of oxygen, for the surface of the ocean is in constant contact with the great body of air. In the case of the animals of the ocean bottom,

this is far from being true; and yet they are constantly supplying to the water a certain amount of carbonic acid gas which in the course of time would tend to so vitiate the water that life could not exist.

This is one of the strongest arguments in favor of a circulation of the waters along the bottom of the ocean, from polar to tropical regions. There must be some supply of oxygen furnished to these deep-sea animals, otherwise they could not exist; and there is no other supply known than that which may be brought by this great oceanic circulation.

Since everything points to the conclusion that this series of ocean movements along the bottom is very slow, it is not unlikely that another limitation to the spread of deep-sea animals, is the lack of abundant oxygen. For if there is not much supplied to the water, there cannot be much taken out. Therefore the existence of life on the ocean bottom, appears to depend upon several conditions which are more or less important; one of these is temperature, another is food supply, and a third is a supply of oxygen.



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The immense mass of information on this subject accumulated by the Challenger is published in an extensive series of over thirty quarto volumes. The set is very expensive; but many of the points of most general interest are found in the two volumes of Narrative and the Summary referred to above.

The Annual Reports of the U. S. Fish Commission also contain much on deep-sea exploration; but it is scattered, and mainly found in the earlier volumes, which are now difficult to obtain free of cost.

CHAPTER X.

OCEAN WAVES AND CURRENTS.

Wind Waves.¹—As a result of friction between wind and water, the ocean surface is readily started in motion in a



FIG. 80.

Ocean waves. Copyrighted, 1871, by Proctor Bros., Gloucester, Mass.

series of wave-like risings and fallings. Normally these wind waves are swells, with alternate ridge-like troughs and crests; but where broken by violent winds, they may

¹For discussion of the effect of waves on the coast, see Chapter XVIII.

be cut into a series of chops or angular crests (Fig. 80). The *water movement* consists of oscillatory risings and fallings of water particles, while the *wave form* passes across the water in the direction toward which the wind is blowing. As the wave passes on, a floating object rises and falls as the troughs and crests of the waves pass over the surface, showing that the water itself is not in horizontal movement. In reality, the friction of the air does drive some of the sur-



FIG. 81.

Breakers on the coast.

face water along, and therefore if a body could float entirely submerged in water, so as to be out of the direct influence of the wind, as each wave passed on, it would continue to rise and fall, but it would also move a short distance in the direction toward which the wave was moving.

When a wave approaches the shore, its form and behavior are greatly changed. The rising and falling particles of water encounter the bottom, the top of the wave combs over,

and it dashes upon the coast in the form of a breaker (Fig. 81). The wave is such a shallow movement in the water that it is readily destroyed upon reaching an irregular coast. Thus in harbors or bays, the violent ocean waves lose their force, largely because of friction upon the shores and bottom.

A very slight breeze will cause a series of wave-like movements or ripples; but as the wind continues, and its force increases, the water surface may be thrown into a series of great undulations. The water is so mobile that these wave movements are transmitted for great distances, and they often extend far beyond the place of origin. One may see this illustrated upon the surface of almost any lake over which a steamer is passing. The series of waves started by the movement of the steamer through the water, extend outward for miles before losing their form. Upon the ocean it is not uncommon to find great swells or rollers, although the sky is clear, the air calm, and the water glassy, — their origin generally being some distant storm.

During almost all times of day, even when the air is quiet, the waves beat upon exposed coasts. When the winds are severe, waves often rise to unusual heights and beat against the coast with terrific violence. They dash against the exposed highlands, sending spray into the air, often to the height of two or three hundred feet; and at these unusual times, great boulders may be wrested from the rocky shore and hurled above the line of the ordinary ocean surface. In some cases, in times of unusual storms, lighthouses have been washed away. Usually the effect of the waves is confined to that part of the coast which is within a few feet of high-tide mark. But during these unusual storms, the action of the wind waves may be extended a number of feet above this point, reaching places which for many years had been

considered safe from wave attack. During a storm, a few years ago, many summer cottages on the sandy coast of New Jersey were attacked and destroyed by the waves, and a railroad that crosses the beach was torn down (Fig. 82).

These effects of waves attract our attention because they are unusual; but the every-day action of the wind waves is also of great importance. They are constantly battering



FIG. 82.

Effect of storm waves on the New Jersey coast.

against the coast and tending to wear it away, while the wind-formed currents and the undertow are important aids in the removal of the loose materials thus wrested from the shore. In many places, as for instance in Boston Harbor, it has been found necessary to build sea walls in order to save from destruction some of the exposed islands which are composed of unconsolidated gravel.

If we watch the rushing of the waves against exposed coasts, or the breaking of the rollers upon the sloping beaches, we are able to form some conception of the vast amount of destructive work that these oceanic agents may do in the course of long periods of time. With every rush of the water upon the beach, pebbles and sand are dragged backward and forward; and this constant friction of one particle upon another, in the course of time will cause even the hardest rocks to wear away. In the course of a few years fragments of brick or glass become rounded, so that they resemble the form of the true beach pebbles; and in a year or two a brick may be reduced to a pebble only a small fraction of the size of the original.

Earthquake Waves. — When an earthquake shock disturbs the waters of the ocean, a great wave is formed, which extends from the bottom of the sea to the surface, and which is therefore much more profound in its effect than the shallow wind waves. In the mid-ocean these earthquake waves may not be perceptible; but as they reach shallow coasts, they may become noticeable as their elevation is increased in the shallowing water. Upon reaching coasts not far from the point of origin, they may have a height of from 50 to 100 feet, which gives them the power of rushing upon the shore to a much greater distance than ordinary waves are capable of reaching.

During some earthquake shocks, the water wave has extended over low coasts and destroyed scores of thousands of lives. Fortunately this form of ocean disturbance is rare, and it is a type of wave which is not common in the Atlantic Ocean. Along the west coast of South America, and on the Asiatic coast, where earthquakes and volcanic eruptions are frequent, the earthquake wave assumes very great importance. It travels at a rate of from three to four

hundred miles an hour, and may extend for a distance of six or seven thousand miles from the place of origin; but at such great distances it has so lost its force that it produces no destructive effect.

Among the important effects of these rare waves is the destruction of life in the ocean. An explosion of dynamite in water will kill the fishes that are exposed to the shock; and near its source, the earthquake wave tends to cause the same kind of destruction.

Storm Waves. — When the great whirling storms of cyclonic origin (the hurricanes and temperate latitude cyclones described in Chapter V.) pass over the ocean, the spirally inblowing winds tend to heap up the water near the center of the storm. In the center the air pressure is less than on the margins, and this also causes the water near the center of the storm to rise. Therefore during these storms there are two tendencies to the production of unusually high water. When the storm centers pass along the coast, the ocean surface is raised to a height often as great as six or eight feet above the average; and if violent wind waves accompany this high state of water, their destructiveness along the shore becomes greatly increased.

Any strong prevailing wind blowing upon the coast, tends to raise the water to an unusual height. During the passage of waterspouts over a portion of the ocean, there is raised a cone-shaped wave, a few yards across the base, which, on a small scale, resembles that caused by the passage of hurricanes.

Ocean Surface Temperatures. — Latitude is the most important cause for differences in atmospheric temperature, and the same is true for the ocean. Near the equator the oceanic waters are warmed, while near the poles their temperature remains approximately at the freezing-point throughout the year. There are all gradations between these two extremes

(Plates 15 and 27). As in the case of the atmosphere, this regularity of distribution is interfered with by outside causes, mainly the influence of land, and air and water movements (Plates 15 and 27). The influence of the ocean currents is shown in both of these maps; and they also show the greater regularity of the ocean surface isotherms in the southern hemisphere, where there is little land.

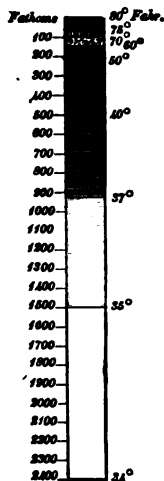


FIG. 83.

Diagram to show the normal descent of temperature in a column of water in the ocean at the equator.

Near the coast the temperatures of the ocean surface are subjected to very marked variations. This is particularly true in the temperate zones, where the difference between summer and winter temperatures is very great. Thus, on the New England coast, the water in summer is warm enough for purposes of bathing, while in winter it is not uncommonly frozen in the shallow harbors. Even at a distance of a number of miles from the shore, this variation from summer to winter is quite marked; but in the mid-ocean, and in the tropical and arctic zones, the summer and winter temperatures are very nearly the same.

In the ocean there is a vertical change in temperature. Since water warms very slowly, the effect of the sun extends only to a distance of a few score of feet, even in the tropics; and below this, the temperature throughout the year is practically uniform, while it rapidly descends until the cold waters of the great ocean depths are encountered (Fig. 83). Because radiation from a water surface is a slow process, the temperature of the water does not become rapidly lowered during the night. Therefore there is very

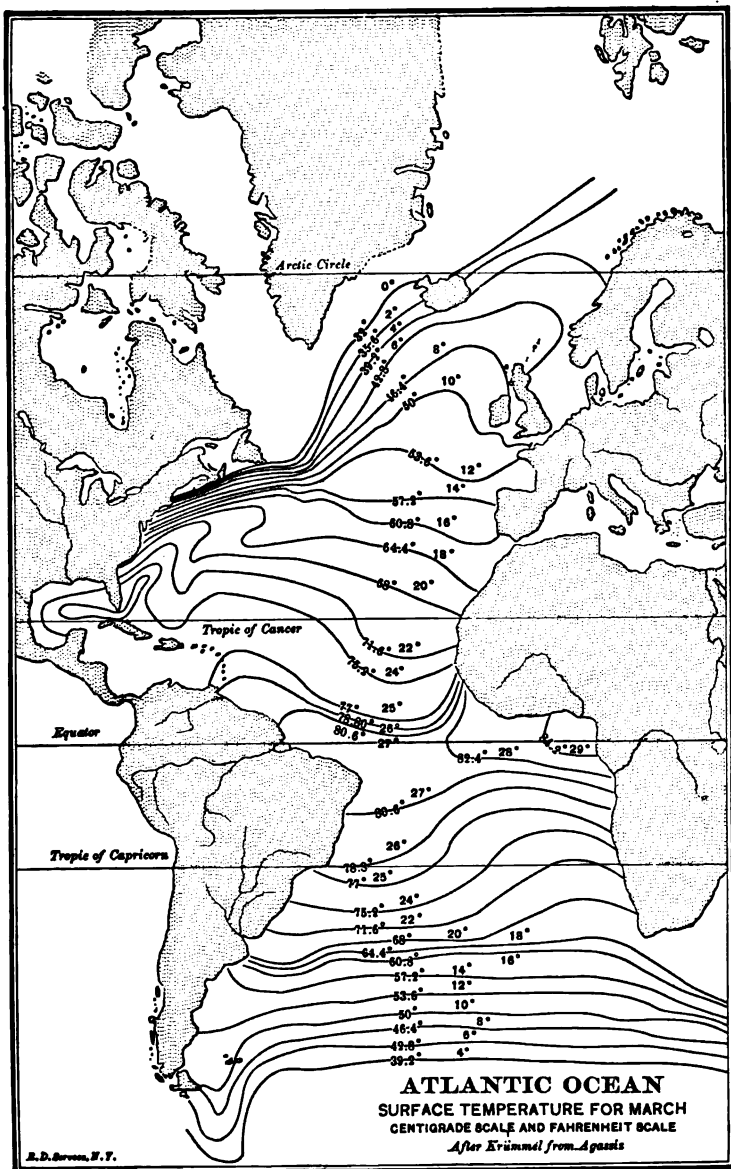


PLATE 15.

little reason for decided changes in temperature, either between the day and night, or between the seasons.

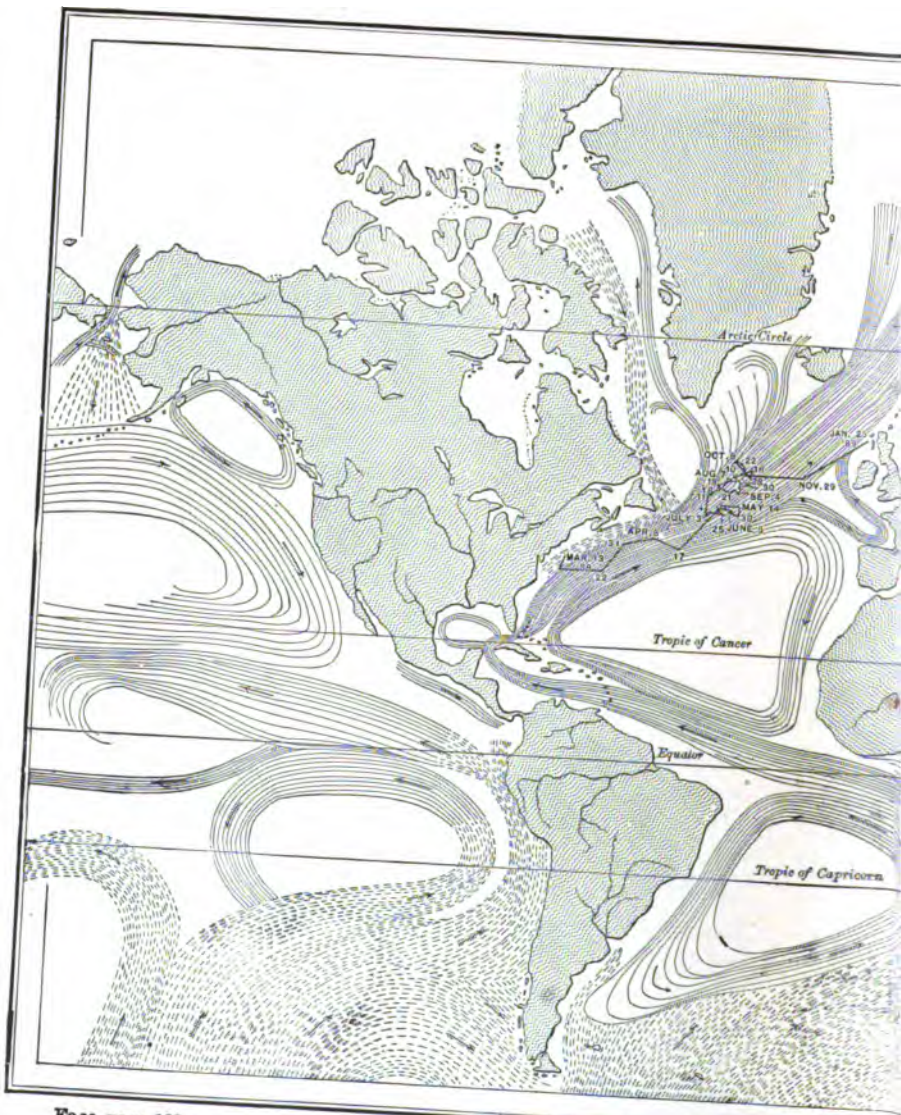
Ocean Currents: Planetary Circulation.—As a result of differences in temperature between polar and tropical regions, the air is engaged in a series of great movements. There are many reasons for believing that a similar circulation exists in the ocean. The fact of the difference in temperature suggests the probability of such a circulation, which would consist of a rising of the water under the equator, a surface outflow from equatorial to polar regions, and then a downsinking to the bottom, from which there would be a return to the equatorial regions along the ocean bottom.

That this theoretical circulation actually exists, is suggested by the fact that the bottom of the sea is inhabited by large numbers of animals. If some such circulation as this did not exist, it would be difficult to account for the supply of oxygen which these creatures need for their existence (pages 171 and 172).

Such planetary circulation seems also demanded by the temperature conditions of the ocean bottom. Unless there has been a downsinking and passage of Arctic waters over the bottom of the ocean, we cannot explain the fact that temperatures as low as the freezing-point of fresh water exist over great areas in the depths of the sea.

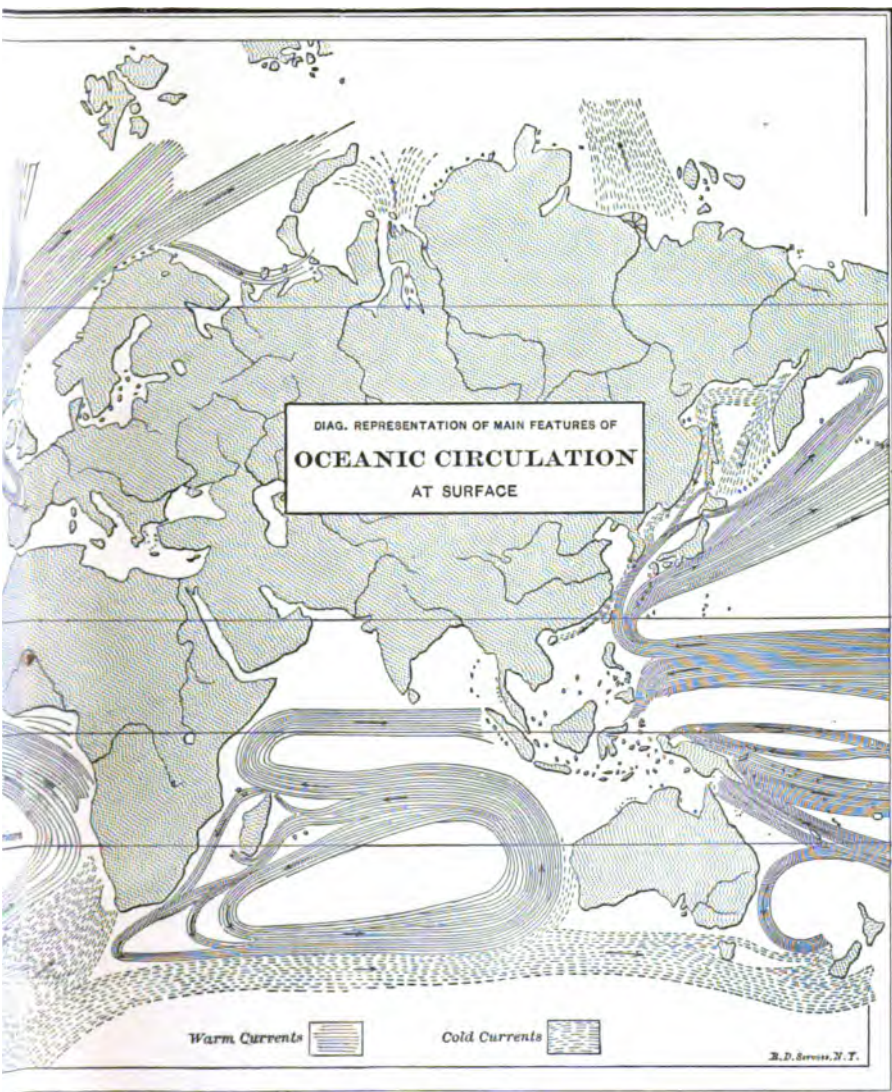
A circulation is also suggested by the peculiar *distribution* of temperature on the ocean bottom. It was stated on page 162 that in some deep parts of the sea, the temperatures are higher than in other portions whose depth is not so great, the apparent explanation being a barrier which interferes with the passage of the slowly moving water over the ocean bottom. Then also, under the equator, a temperature of 41° is encountered at a depth of 250 fathoms, while in the





Face page 183.

PLATE



northern hemisphere this temperature is reached at a depth of about 600 fathoms, and in the southern hemisphere at a depth of about 400 fathoms. This indicates that under the equator the cold water of the ocean bottom is rising.

The System of Ocean Currents. — (Plate 16.) We know little concerning the circulation of the water on the sea floor; but at the surface there are certain very distinct movements, to which the name ocean currents is given. In the Atlantic there is a drift of surface water toward the equatorial portion of South America. This slowly moving surface water divides against the triangular coast of South America, one portion passing southward, the other and larger part moving northward, still as a slowly moving drift.

A considerable part of the north-moving drift passes into the North Atlantic outside of the West Indies, and this may be called the *North Atlantic Drift*. The portion which enters the Caribbean, passes through the Straits of Yucatan into the Gulf of Mexico, where a part of it circles around, and finally emerges past Key West at the southern end of Florida. Some of the water passes northward between the West Indies. Therefore, by the time it has reached the latitude of the Carolinas the warm current of the North Atlantic is composed of several parts.

The portion which emerges from the Gulf of Mexico between Cuba and Florida, is known as the Gulf Stream; and this passes northward along the coast as a very perceptible current, on the seaward side of which is a portion of the Atlantic drift, which did not enter the Gulf of Mexico. At about the latitude of Cape Hatteras, the Gulf Stream is turned to the right as a result of the influence of the earth's rotation, and it then passes out into the Atlantic until the

European shore is neared.¹ A branch extends northward into the Arctic, while a part returns as a surface current along the coast of Spain and Africa, there joining the equatorial drift. The water thus eddies around in the North Atlantic, moving northward, then eastward, southward, and southwestward, thus establishing a complete whirl. Another important current in the North Atlantic is the cold Labrador current (see p. 189).

In the South Atlantic a similar whirl of water is caused ; but this is distinctly less pronounced than that of the North Atlantic, and there is no current so marked as the Gulf Stream. Cold water from the Antarctic extends northward into the South Atlantic.

In the North Pacific, a circulation is established which very closely resembles that of the North Atlantic. A broad equatorial drift passes westward toward the Asiatic coast, then becoming in part a north-moving current, it proceeds as a very distinct stream, in many respects resembling the Gulf Stream. This is known under the name of the Kurc Siwo, or better as the Japanese current. It passes northward, is turned to the right, then moves southeastward, bathing the western coast of the United States, then curving to the southwest, it joins the equatorial drift. Owing to the fact that land practically excludes the Arctic waters from the North Pacific, there is no distinct Arctic current in this ocean, nor is the Japanese current able to extend a large branch into the Arctic. Still a small current of cold water does pass through Bering's Straits into the North Pacific.

In the South Pacific and Indian oceans, distinct whirls of

¹ Numerous observations on the movements of wrecks and floating bottles have given us much information concerning this current. One set of observations upon a floating wreck is shown on Plate 16.

water are produced, which more nearly resemble the whirl of the South Atlantic than those of the northern oceans, but which nevertheless are better developed than the South Atlantic system of currents. Cold currents from the Antarctic extend into both of these oceans.

Thus we find a great series of whirls in the oceans, one on each side of the equator in each ocean, the water passing poleward as surface currents and in part returning to complete the whirl. The north-moving system is better developed than the return south-moving currents, and the system of ocean currents is much better developed in the northern than in the southern oceans. Particularly is this true of the Atlantic. In any explanation of oceanic circulation these facts must be accounted for.

Cause of Ocean Currents. — Although there is evidence that a planetary circulation exists in the ocean, there are many reasons for doubting whether this cause is sufficient to explain the system of surface currents which is so well developed. The difference in temperature does not seem sufficient to account for the great oceanic whirls. While the almost constant cold of the Arctic and Antarctic oceans causes a continual descent of water, it cannot be said that the heat at the equator is sufficient to so expand the water as to cause surface currents to start here.

The comparison has been made between the ocean circulation and that of the air; but this is only partly warranted, for the air is warmed from below by contact with the earth, and when warmed this lower air must rise. In the ocean, the heat of the sun is practically confined to the immediate surface; and this relatively thin layer is not warmed to a very high degree, so that its expansion would not seem to be sufficient to cause a flowing away. If the sun's heat penetrated to the ocean bottom, the warming of the lower

layers of water would cause sufficient expansion to necessitate their rise to the surface ; but this is not the case.


If temperature differences account for ocean currents, the fact of the greater development of the system in the northern oceans would be difficult to explain. The Antarctic is practically open to both Atlantic and Pacific, and in that hemisphere there is an excellent opportunity for an exchange of polar and tropical waters. But the Arctic is almost completely shut off from the Pacific, and is only open to the Atlantic through narrow and rather shallow channels. Therefore, in the hemisphere where the least favorable conditions for an exchange of water exist, we have the best developed currents. In the North Pacific there seems absolutely no chance for the general passage of cold northern waters along the bottom to the equator.

This and other reasons, such for instance as the presence of cold surface currents returning from the Arctic, cause great doubt as to the validity of the temperature theory which has been held by many physicists. It seems that we are forced by these arguments to return to the theory which was proposed by Benjamin Franklin, who pointed out the fact that nearly permanent winds are blowing toward the equator throughout the year. These trade winds necessarily drive large quantities of surface water before them, just as the winds along the coast will cause the surface water to drift before them.

Thus the water is being heaped up in equatorial regions, and this seems sufficient to account for the great whirls ; and there are many facts tending toward the conclusion that winds are the prime cause for these currents. Among other things, the whirls are best developed in the northern oceans. The belt of calms, which separates the two systems of trade winds, is mostly north of the equator, and the northern belt

of trade winds does not extend south of the equator during the northern winter, while the southern belt does extend north of the equator during the northern summer (Plates 10 and 11). Therefore there is a greater drift of water in the northern hemisphere than in the southern. Probably the differences in temperature aid in this circulation; but to this cause we must assign a secondary importance.

The course of the various currents is in part determined by the outlines of the continents. If there were no continents, the effect of the trade winds would be to produce a surface drift, which would tend to pass around the earth, approximately in the belt of calms. The north and south extension of land in the form of continents, interferes with this circulation, and causes the moving water to pass northward or southward. After this deflection, there is a continued tendency for the currents to turn, under the influence of the earth's rotation, to the right in the northern, and to the left in the southern hemisphere. These two facts of continental interference, and deflective effect of the earth's rotation, are mainly responsible for the paths pursued by the currents, and for the great system of whirls. The cold surface currents which come from the Arctic and Antarctic, are probably a partial return of the warm water that drifts into these zones.



The Gulf Stream. — This, which is the best-known of ocean currents, is of so much interest to us, and so well illustrates some minor phenomena of ocean currents, that it is well to examine it in a little more detail than has been done (Plate 17). The Gulf Stream proper is that portion of the equatorial drift which has passed through the Caribbean and the Gulf of Mexico. During its passage through these warm gulfs, its temperature has been increased so that it emerges into the Atlantic as a very warm current. It is

one of the most rapidly moving of ocean currents, and its rapidity depends upon the peculiar effect of irregularities in

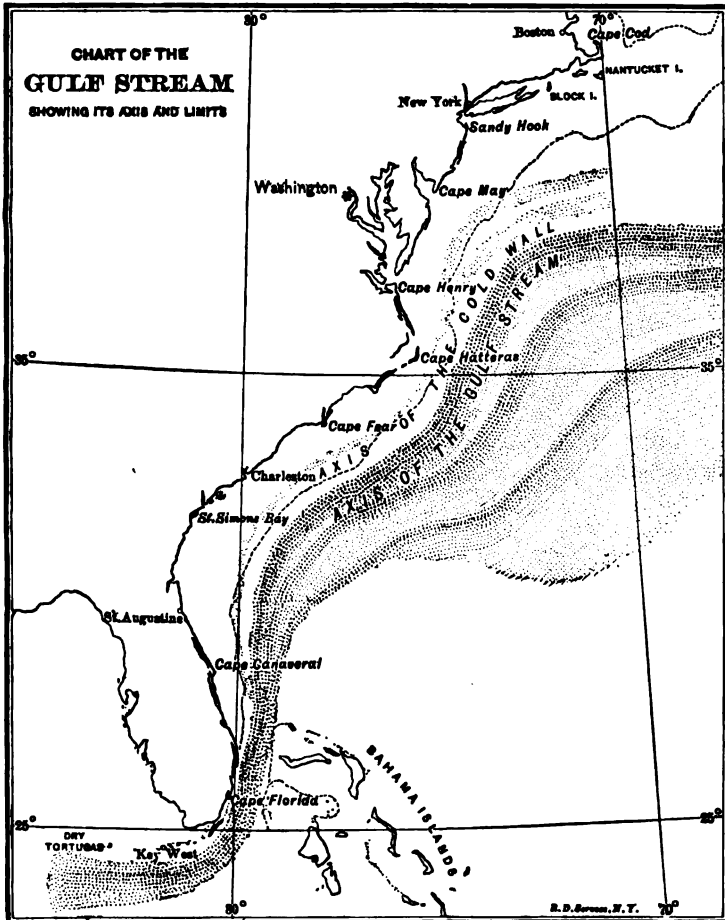


PLATE 17.

the continental outline. Passing into the Gulf of Mexico without difficulty, it finds itself partially enclosed. The one

place of easy escape is in the narrow passage between Key West and Cuba. In a measure, it is concentrated here, in a manner somewhat analogous to the concentration of water in the nozzle of a hose.

When it passes through the channel at the end of the Yucatan peninsula, its velocity is only about $\frac{1}{4}$ of a mile an hour, and its width is about 90 miles, while its depth is approximately 1000 fathoms. When it emerges past Key West, its velocity is from four to five miles an hour, its width only 50 miles, and its depth about 350 fathoms. If it were not for this concentration, the Gulf Stream would not be such an important factor in the North Atlantic. Soon after passing through this narrow channel its velocity decreases; and by the time it has reached the Banks of Newfoundland, its rate of movement is less than half that which it had on the Florida coast. It has been estimated that every day, the Gulf Stream carries past Florida the enormous amount of 436,000,000,000,000 tons of water.

The Labrador Current. — The Labrador current comes from the Arctic between Greenland and Labrador, passing down the coast of Nova Scotia and New England, and keeping close to the coast, because of the influence of the earth's rotation, which tends to make it curve to the right. It remains as a surface current until Massachusetts Bay is reached, where it sinks to the bottom, owing to the fact that it has a lower temperature, and therefore greater density, than the surrounding water. But its influence is felt upon the continental shelf nearly down as far as Cape Hatteras.

Effects of Ocean Currents. — The most striking effect of currents is upon the temperature. If it were not for the existence of this oceanic circulation, it is probable that a large part of the now habitable earth would be rendered unfit for habitation. Much of the heat received in

equatorial regions would remain there, while the cold of high latitudes would increase, and the temperature in these regions would be reduced to very low degrees. The equatorial regions would be much hotter than at present, while the high temperate and arctic belts would be colder. The immense influence of these currents is shown by the fact that in the latitude of Labrador, — a bleak, inhospitable land, — there are powerful and well-populated countries on the other side of the ocean. In the one case, cold Arctic currents flow along the coast; in the other, the climate is tempered by the warm ocean current.

Ocean streams carry vastly more heat than air currents are capable of doing. Croll has estimated that the Gulf Stream alone carries as much heat as falls upon a surface of 1,560,935 square miles at the equator. He says that this stream carries from tropical regions, nearly one-half as much heat as is received directly from the sun in the entire Arctic.

The temperature of the Pacific coast of the United States is greatly moderated by the warm Japanese current, which carries into the North Pacific a large store of heat; and, both on this coast and on the western coast of Europe, the warm bodies of water which are off-shore, not only supply quantities of heat, but they furnish to the land much moisture which is condensed in the form of rain.

Franklin's attention was called to the Gulf Stream by reason of the fact that sailing vessels made their voyage from the colonies to the mother country in a shorter time than on the return. Therefore, in some cases, currents in the ocean are an aid to navigation (see Plate 16, showing the drifting of a wreck in this current). Where a cold and warm current are side by side, as is the case near Newfoundland, fogs are abundant, and this interferes with navigation.

Since the currents temper the ocean waters (see Plate 15), they tend to modify the conditions upon which the spread of marine animals depends. This influence is particularly noticeable among the coral reefs. The warm tropical currents carry large quantities of food and of clear water to the banks upon which corals are developing; and it may be said that in this indirect way, ocean currents are an important cause for coral reefs. Thus, where the Gulf Stream bathes the coast of Florida, reefs and coral keys are produced; and even as far north as the Bermudas, coral life is possible because of the presence of the warm tropical current.



REFERENCE BOOKS.

In many of the books referred to at the end of the last chapter, there is something on oceanic movements. See particularly Agassiz, Wild, and Thoulet.

For a very complete discussion of ocean currents, see Croll's "Climate and Time," referred to at the end of Chapter VII.

Maury. — **THE PHYSICAL GEOGRAPHY OF THE SEA.** (There are many editions of this book, most of them, and the best, being out of print and obtainable only in the second-hand condition.)

Pillsbury. — **THE GULF STREAM,** "U. S. Coast Survey Annual Report for 1890," Appendix 10. Washington, 1891. Issued by the survey in separate form. (The most complete discussion of the Gulf Stream which has been printed.)

BERGHAUS ATLAS, VOLUME ON HYDROGRAPHY. Justus Perthes, Gotha, Germany, 1891. 15m. (Contains numerous excellent charts of currents, ocean temperatures, etc.)

CHAPTER XI.

TIDES.

Nature of the Tidal Wave. — Each day the ocean surface is disturbed by two waves which pass about the earth with great rapidity (fully 500 miles an hour in the Atlantic), and affect the entire ocean, from surface to bottom. The actual height of the tidal wave is very slight, and sailing vessels in the mid-ocean are never aware of its existence. When it approaches the shore, the wave is subjected to a variety of complex changes, which make it an important feature of the ocean. On the coast, the water gradually rises or *flows*, and as gradually falls or *ebbs*; and this is repeated, with marked regularity, approximately twice each day.

Cause of Tides. — In origin, the tide is directly associated with the effect of the moon and sun upon the earth. All bodies in space are engaged in a mutual attraction which we know as gravitation; and the effect of this gravitative attraction is proportional to the product of the masses, and inversely proportional to the square of the distance. Every member of the solar system is exerting an attraction upon the earth. Since the attraction varies with the mass, such a large body as the sun would produce a great effect if its distance were not so great. The moon, although relatively small, is so near that its influence upon the earth is much greater than that of the larger and more distant sun.

Leaving the sun out of the question for a time, let us see what effect the attraction of the moon will have upon the

earth. If the earth were all liquid, the attractive action of the moon would tend to destroy the sphere and change it to an ellipse. The ellipse would project toward the moon, for that portion of the earth's surface which was nearest the moon would be most attracted. Since the rotation of the earth causes the moon to appear to pass through the heavens, this ellipse would constantly change in position, with its axis always pointing toward the moon. Therefore the liquid sphere would be thrown into a series of waves, one crest being beneath the moon, while the other crest was on the opposite side of the earth farthest from the moon.

This is approximately what happens in the liquid ocean. The surface of this partial liquid covering is disturbed by the gravitative attraction of the moon, and a wave is thus produced beneath it, while one is also formed on the opposite side of the earth. As the moon appears to pass around the earth, these two waves also move. They are much disturbed by the irregularity of the continents, and their movements are rendered very complex as a result of this influence. They are not able to remain directly beneath the moon, but lag behind and follow it, instead of passing around the earth with it.

In a similar manner the sun causes two waves; and these combine with those produced by the moon to produce the tidal wave. Since the movements of the sun, the moon, and the earth are very irregular, there are many complexities introduced into the tidal movement. In the latter part of the chapter some of these irregularities are considered, and their cause pointed out.

Effect of the Land. — The tide waves tend to pass about the earth from east to west, following the direction of the path of the moon through the heavens. This west-moving tide wave is much better developed in the great expanse of

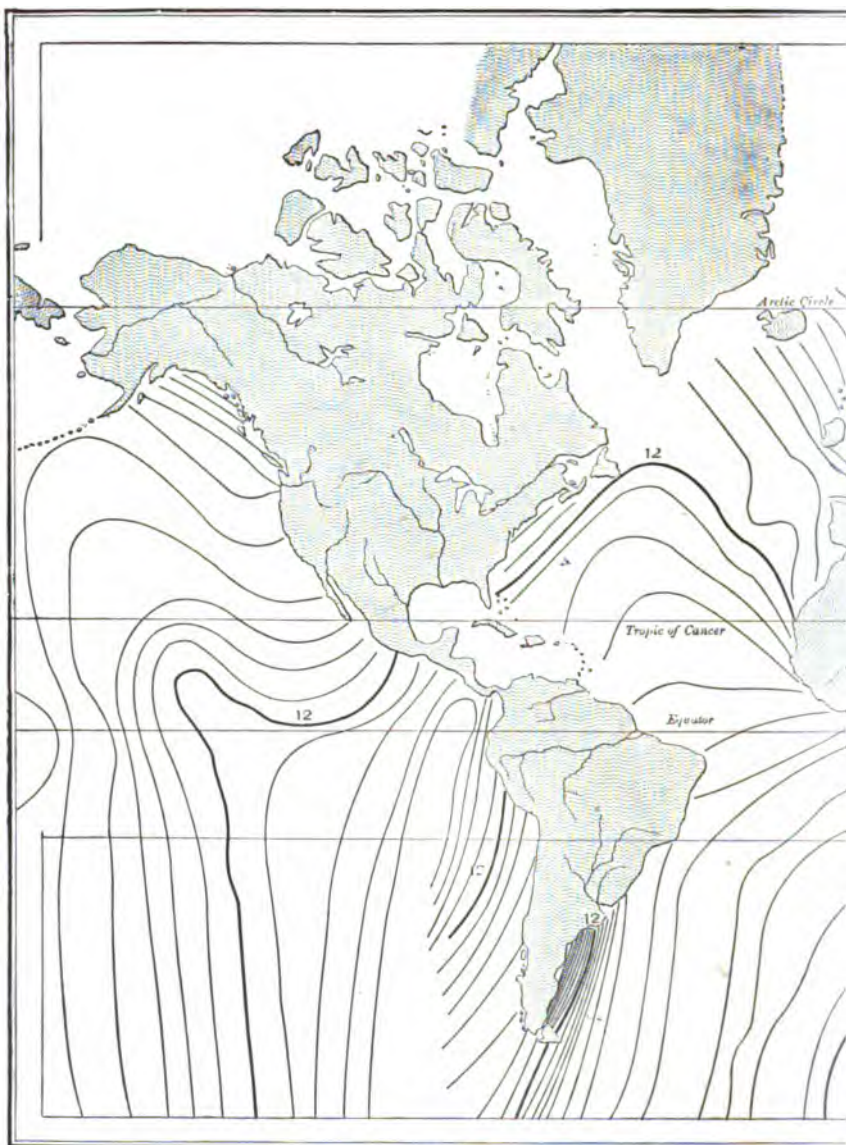
water in the southern hemisphere, than in the northern. The continents interfere with the movement of the wave, and in some cases successfully check it. When the wave enters the Atlantic, its direction is changed from west to north, and soon the wave is so changed that it advances more rapidly in the middle part of the ocean than on the margins (Plate 18). This is due to the effect of the shallow waters near the continents. The wave is retarded near the shore and advances more rapidly in the central portion of the ocean. As a result of this, the crest of a wave may have reached the latitude of Newfoundland at the same time that the margins are affecting the coast of northern Africa and the West Indies.

In a similar way this effect of friction is also shown in the bays and larger estuaries. Thus as the wave passes up the Bay of Fundy, friction with the shore causes it to be retarded, while in the central part of the bay the wave advances more rapidly.

Nowhere can this effect of the land be better illustrated than in the vicinity of the British Isles (Plate 19). The wave passes up the Atlantic, and without serious interference moves to the northern extremity of Ireland and Scotland, while the same wave has advanced to the southern coast of England, and begun to pass into the English Channel. The shallowness of the water in this region prevents the rapid movement of the wave; and by the time it has passed through the English Channel, the part that went outside of the British Isles has gone entirely around the islands, and entered the North Sea, where the two parts of the same wave meet (Plate 19).

On the American coast a similar influence of the land is noticed in the approaches to New York Harbor. The tidal wave passes readily up the bay toward New York, while the





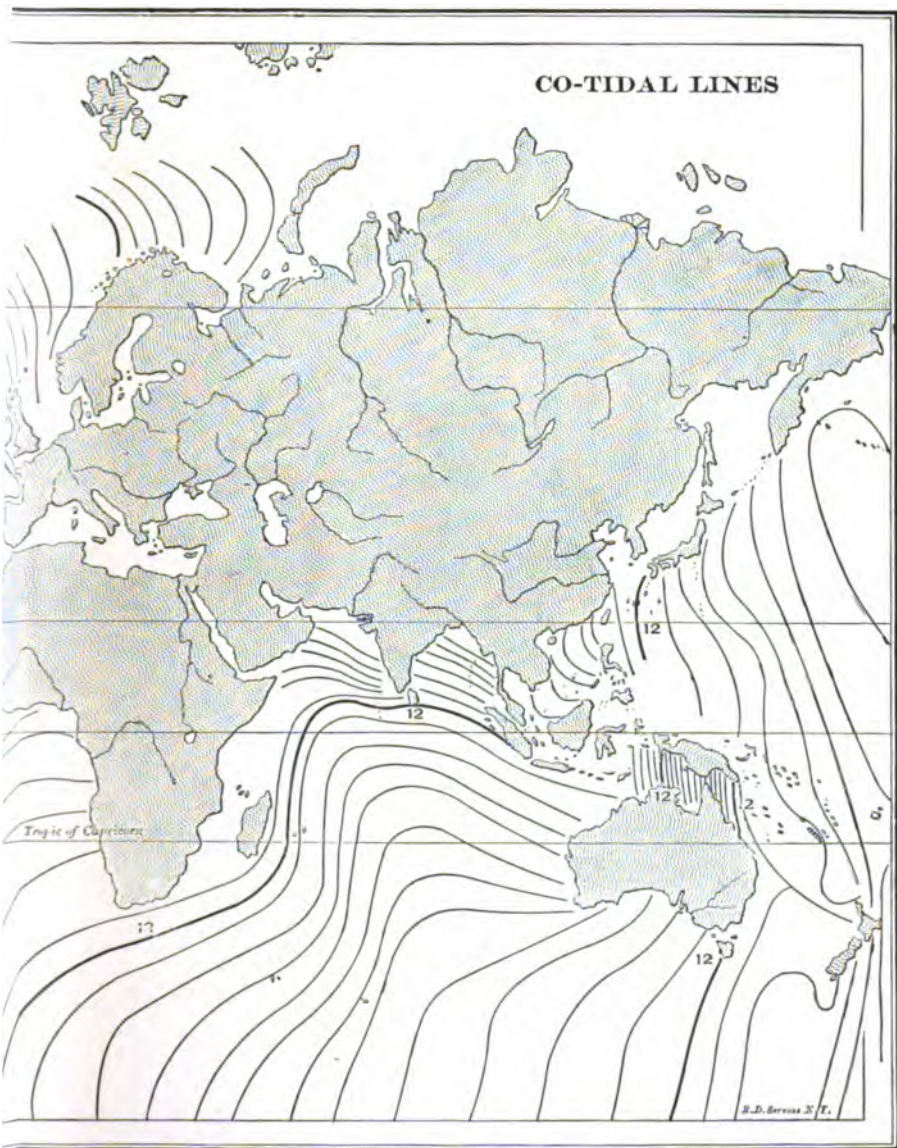


PLATE 18.

of the tidal waves. Figures refer to noon and midnight.

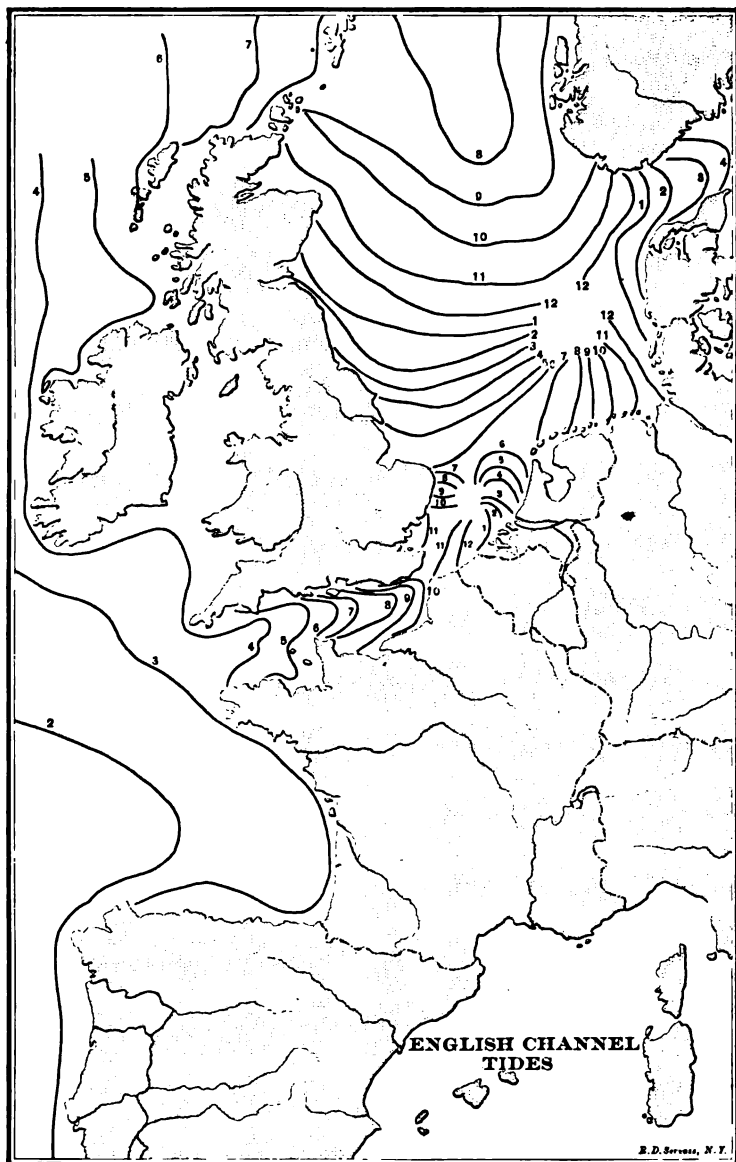


PLATE 19.

Diagrammatic representation of the tidal wave near the British Isles. Figures refer to hours of the day.

same wave goes around the eastern end of Long Island into Long Island Sound (Fig. 84). Here its rate of motion is



FIG. 84.

Diagram to show path pursued by the tides on the two sides of Hell Gate. Figures represent height of tides at different places.

retarded, the distance traveled is greater, and at Hell Gate Channel the two parts of the same wave arrive at entirely different times (Fig. 85). This is one of the reasons for the violent currents at Hell Gate.

Aside from this influence of coastal irregularities upon the *time of approach* of the tidal wave, these peculiarities also influence the *height* to which the tide rises. The normal tidal rise, as observed in mid-ocean and on exposed coasts, is only one or two feet. Along the eastern coast of America, we find the tide rising in one place only two or three feet, in other places 10 or 20 feet, and in the Bay of Fundy often 50 or 60 feet. These irregularities are due to the influence of the coastal outline.

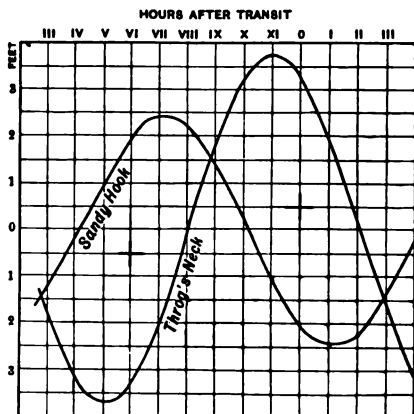


FIG. 85.

Diagram to show time of arrival and height reached by the tides on the two sides of Hell Gate.

There are two ways in which the tide may be almost entirely destroyed. It is a familiar fact, that if two waves meet trough to crest, they extinguish one another. It is believed that the two tidal waves which meet in the North Sea (Plate 19), actually come together in this way.

When the tide enters a large body of water through a narrow inlet, the tidal rise is almost entirely destroyed, as is very well illustrated in the Mediterranean. Outside of the Straits of Gibraltar, on the coast of Spain, the height of the tide is from five to six feet. The wave enters the Mediterranean through this narrow inlet, then expands, and consequently loses in height, until almost no tide is left. In portions of the Mediterranean there are slight tides, but these appear to depend in part upon another cause.

The opposite effect of *increase in height* of the tide is by far the most common influence of coast irregularities. When, instead of entering a large body of water through a narrow inlet, the tidal wave passes into a narrowing bay through a broad mouth, the effect of the converging shores is to pile up the wave, and therefore to increase the height of the tide. This is the cause for the very high tides of the Bay of Fundy, and many other V-shaped bays and estuaries. It is well illustrated in Massachusetts Bay, where the rise of the tide is between 8 and 12 feet.

As a result of the influence of coast irregularities, some peculiar tidal effects are produced. In two neighboring, and possibly connected bays, the height of the tide may be quite different. This is the case in Vineyard Sound and Buzzard's Bay, on the south coast of Massachusetts, where, in the latter, the tide rises one or two feet higher than in Vineyard Sound, which is open on both ends. In the channels which connect these two bays, violent currents are produced; and this whole region, between the Elizabeth Islands and

Nantucket, is one of relatively rapid tidal currents. The rapid currents in the straits between two such bodies of water, may be called *tidal races*.

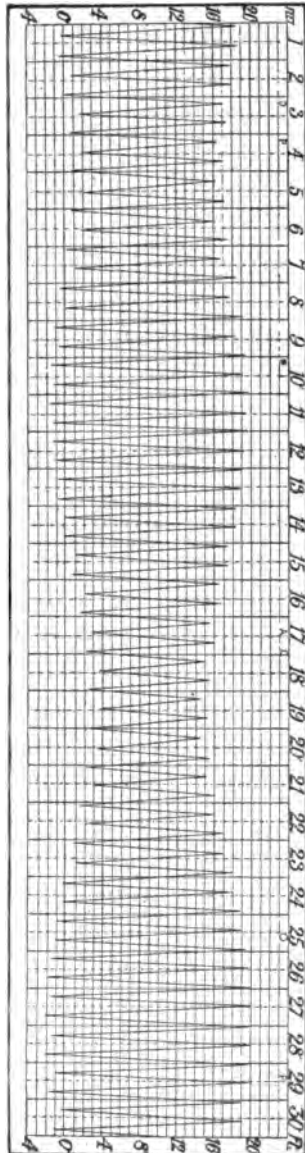
A tidal race is produced at Hell Gate, near New York City, mainly because the tide rises higher in Long Island Sound than it does in the bay of New York Harbor (Figs. 84 and 85). The very rapid currents in this shallow strait, are in part due to this cause, and in part to the fact that the time of high tide is different on the two sides of Hell Gate. Similar tidal races occur on many parts of the irregular northern shore, and at times currents are produced which are as violent as rapidly moving streams. In some cases it is impossible to row a boat against the current.

In a rapidly narrowing bay, particularly at the mouth of a river, the rising tide is sometimes transformed to a wave, which in form resembles the wind wave; and there is an advancing wall of water, instead of the gradual, almost imperceptible rising of the ocean surface, which is the normal form of the incoming tide. To this peculiar phenomenon the name *tidal bore* is given. This wave is produced in the Amazon, the Severn, the Seine, and many other rivers.

Other Causes for Variation in Tidal Height. — At any given point on the coast, the height of the tide is liable to vary from time to time. This variation may be of an irregular nature, due to the effect of winds upon the surface of the water. Sometimes, when strong winds blow upon the coast, the height of the tide may be increased several feet. A mere change in the pressure of the air also appears to cause fluctuations in the surface of the sea; and upon lakes, these causes produce fluctuations in level which are often of quite noticeable size. In the Swiss lakes these irregular variations in the level of the water are known as *seiches*, and they are also found upon the Great Lakes.

The main variations in the height of tide depend upon astronomical causes. Since the tide is the combination of two waves, one produced by the sun, and the other by the moon, the height of the tide naturally varies as the position of these bodies in the heavens changes. During new moon, the sun and moon are nearly in the same line, and they therefore pull approximately along the same line, so that the unusually high tide then produced (known as *spring tide*), is the result of a combination of the two waves. During full moon, the sun and moon are again in line, one on either side of the earth, and then the two waves again tend to combine. Therefore every month there are two sets of rather strong or high tides (Fig. 86). Between new and full moon,—that is, during the first and third quarters,—the sun and moon

Diagram showing the rise and fall of the tide at Eastport, Maine, for the month of September, 1893. Phases of the moon also shown: shaded circle, new moon; plain circle, full moon. P, perigee; A, apogee.



are pulling upon the earth at an angle, and then unusually weak or low tides, known as *neap tides*, are produced.

In the movement of the moon around the earth, it follows a path which is quite elliptical. Therefore, since the earth is at one of the foci, there is a time during every lunar month when the moon is much nearer the earth than when it is in the opposite part of its elliptical path. When the moon is nearest to the earth, it is said to be in *perigee*, and when farthest from the earth, in *apogee*. Since the tide-producing force varies greatly with the distance, this difference in lunar distance produces a very marked effect upon

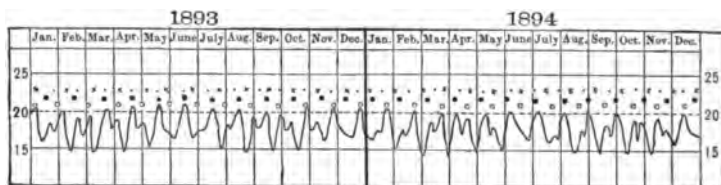


FIG. 87.

Height of the high tide at Eastport, Maine, in 1893 and 1894. Cross indicates apogee; dot, perigee; shaded circle, new moon; plain circle, full moon.

the strength of the tide. Thus it will be seen that when the new or full moon comes during perigee, a high range of tides will result, because then the moon is both nearer to the earth, and its tide is combined with that caused by the sun. If new or full moon occurs during apogee, the tides are not so strong, because then, although the solar and lunar tides are combined, the moon is farther from the earth. When apogee occurs at one of the quarters, the tides are unusually low; and when perigee occurs at this time, the effect of opposition of sun and moon is partly counterbalanced (Figs. 86 and 87).

Other movements of the earth, sun, and moon introduce complexities in the tidal rise and fall. For instance, in some

seasons the sun is nearer the earth than at others, and at times the moon is more nearly over the equator than at other times; and all of these variations produce an effect upon the tide. One notices in Fig. 86 that the two tides for any single day are different in height; and this difference varies in various parts of the month. All of these irregularities are capable of explanation, and are well understood; but it will be impossible to give the space for their consideration in this book.

One point is worth special attention,—that the time between two high tides is not exactly a half day, because the tide wave travels on lunar, and not on solar time. The tide rises once every 12 h. 25 m., so that each day the high tide is about 50 minutes later than the corresponding tide for the previous day.

Effects of Tides.—Along irregular coasts, where the tide rises to a height of several feet, and where tidal currents are produced, the influence of the rise and fall of the tide is of considerable importance in navigation; and before sailing, many vessels wait until a favorable time of tide. This is particularly the case when ships are about to sail from ports that are obstructed by bars, which at low tide are so near the surface that some ships are unable to pass over them. This is the case in many harbors of the world.

Because they are much less powerful, tidal currents are not wearing the coast in the way that wind waves are; but they are doing a certain work in changing the form of the coast, mainly as the result of transportation of fragments derived from the rocks by the beating of the waves. On some coasts, as for instance in the English Channel, and near Nantucket, the action of the currents, by the constant movement of the sands, is sufficient to cause frequent changes in the depth of the water.

Where the tide rises in the mouths of rivers or in estuaries, as in Chesapeake and Delaware bays, the rise of the tide checks the river water, and causes it to deposit what sediment it is carrying, so that this effect is also important in modifying the bottom of these bays (Fig. 88). Many harbors are being filled by this means, and millions of dollars are every year expended in attempting to remove the mud and sand deposited by this tidal action.



FIG. 88.

Low tide in Basin of Minas, Nova Scotia. An extensive mud flat, submerged at high tide. (Copyright, 1890, by S. R. Stoddard, Glens Falls, N.Y.)

The rise and fall of the tides is a great force in the ocean (Fig. 89), constantly acting, and capable of doing a great amount of work, which man may sometime find it possible to utilize. Already, in some places, the rising and falling tides are employed for local purposes of water power. On the New England and Canadian coast, the rising tide is allowed to freely enter some broad, bay-like expansion of the coast, from which it is prevented from escaping by means

of gates that automatically close as the tide begins to fall. There is then produced a rather large pond, several feet above the low-water mark; and from this, water may be led upon a wheel, and then made to serve for mill purposes. There are numerous grist mills along the coast which are run by tide-water power. They can be used only a few hours every day, but it is a very expensive power. The introduction of electricity for so many uses, may make it possible to employ this vast force much more commonly than has been done.



FIG. 89.

Coast of Cape Ann, Mass. To show tidal rise and fall. The dark-colored areas are covered by the high tide.

REFERENCE BOOKS.¹

Thomson.—POPULAR LECTURES AND ADDRESSES. Vol. III., Lecture on the Tides. Macmillan & Co., New York, 1891. 12mo. \$2.00. (A partial statement of the tidal theory).

See article on tides in Encyclopedia Britannica.

For data upon time and height of tides, see TIDE TABLES FOR THE ATLANTIC COAST, U. S. Coast Survey, Washington, D.C. \$0.25. Published annually. There is also a similar set of tables for the Pacific coast.

¹ The subject of tides is difficult to present clearly in non-mathematical terms, and hence the general literature is quite barren upon the subject. By far the most that has been written upon the subject, is scattered through the proceedings of scientific societies and the magazines.

PART III.

THE LAND.

CHAPTER XII.

THE CRUST OF THE EARTH.

Interior Condition. — Some wells and mines have extended to a depth of over a mile from the surface, and in every case it is found that the temperature increases as the depth becomes greater. While this increase is not regular, on the average it is about 1° for every 50 or 60 feet of descent. If this increase continues, as it probably does, the temperature at the depth of a score of miles, is sufficiently high to melt most rocks under the conditions existing at the surface. In various parts of the earth, molten rock reaches the surface through volcanic vents; and there are other indications that high temperatures exist within the earth.

Until within a few years, it was believed that beneath a crust of comparative thinness, the earth was in a molten condition, and that the solid crust, or rind, rested upon this liquid. In speaking of the outside of the earth, we still use the term *crust*, although it is no longer believed that the interior is molten. Many facts, some astronomical, others geological, have caused the abandonment of the theory of a molten interior; and it is now believed, that although at depths only a few miles from the surface, the temperature is high enough to melt rocks, they are prevented from becoming molten by the great pressure of the solid strata of the crust. This energy is constantly passing from the interior to the surface, where it is radiated into space; and this constant loss of heat causes a loss of bulk through con-

traction. The cold outside does not shrink; but as the interior loses in size, this crust becomes wrinkled, in a manner which may be compared with the wrinkling of the skin of an apple which is drying.

Movements of the Crust. — There are many proofs that the crust of the earth is in movement. Usually these movements are so slow that they can be detected only after long intervals of time; but sometimes rapid changes have actually been witnessed. The proofs of these earth movements may be said to be of two kinds, historical and geological. While the historical proofs may perhaps appear to be most conclusive, they are in reality much less important than those of a geological nature.

In several places the land has been known to move during earthquake shocks, and to remain either higher or lower than before the shock. As one instance of this, we may refer to the earthquake of 1822, during which the whole coast of central Chili was raised from three to four feet. In other shocks on the same coast, the land has been permanently elevated, and there is abundant evidence that the land of this coast is now steadily rising. Near Vesuvius, in Italy, there are columns of a temple which were built above the level of the ocean, and are now above it, but which at one time were submerged; and they therefore register two movements of the land. On the coast of Sweden, it was believed that the land was slowly moving, but so slowly that without careful measurements it could not actually be proven. In order to thoroughly test the matter, marks were made at the water surface, and after a number of years examined, when it was found that there were movements over an area of 200 miles in extent. North of Stockholm the rate of elevation is as much as two or three feet a century.

Of geological evidence, perhaps the best is that of fossils,

which have attracted attention from the very earliest times. Remains of animals that must have dwelt in the sea, are found in many of the rocks of all continents, and at all elevations, even on the highest mountains. The rocks themselves are evidence of elevation, for in many cases they are of kinds which we know must have been formed in the sea.

Along the coast lines, in many parts of the earth, beaches and other features of the seacoast are found at a distance above the present sea level; and tree trunks which we know must have grown on the land, are in some cases below the low-tide mark. The shore lines of lakes which once existed in the interior, but have now disappeared, also give evidence of land movement. Since they were formed on the margin of a level body of water, they must have been horizontal; but in some cases these ancient shore lines are no longer horizontal. Other evidences might be brought forward in proof of a change in the relation between the sea level and the land.

It may be asked whether this is proof of changes in the level of the sea, or of land movement. While there is reason to believe that there have been changes in the sea level, the evidence is conclusive that the greater number of these changes in relation of land to sea, are due to actual movements of the land. Without entering into this subject in detail, it may be stated, that the most conclusive evidence that this change is due to land movement, is the fact that many of the rocks, which we know were formed as nearly horizontal layers in the ocean, are now found in mountains in a folded and often broken condition.

Disturbance of the Rocks.—In many cases, the rocks that have been raised from the sea, to form a part of the continent, are still in nearly horizontal positions (Figs. 90



FIG. 90.

Horizontal rocks on the plains of Kansas.

and 133 and Plate 28). They have been bodily raised with very little disturbance. In mountains, and less prominently elsewhere, the rocks have been moved from their horizontal position, and caused to assume inclined attitudes, which are

often very complex. These changes commonly assume one of two forms, either (1) folding or (2) breaking, which we call faulting.

Even the most brittle of rocks may be folded. The cause for the folding usually acts so slowly, and the rocks are under such pressure from above, that they bend, rather than break, when subjected

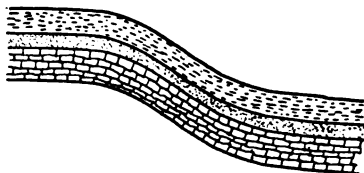


FIG. 91.

A monocline fold.

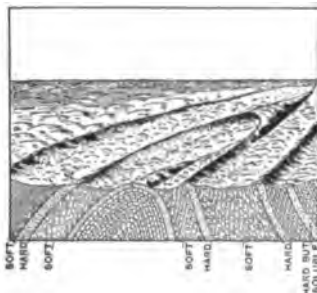


FIG. 92.

Anticline.

to a strain such as that which comes from contraction of the interior. A simple kind of fold is that known as the *monocline* (Fig. 91), where the rocks are inclined in only one direction. When they are bent up in the form of an arch, the folds are known as *anticlines* (Fig. 92), and the corresponding down fold is known as the *syncline*

(Fig. 93). These may be no more than a few inches across the base, or they may have a width of several miles, with a length of perhaps a score of miles.

Among mountains there is often an extremely complex system of disturbances, the nature of which can best be under-

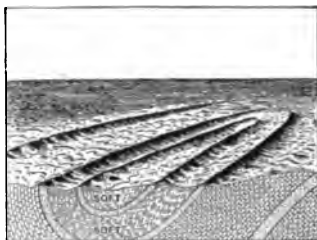


FIG. 93.

Syncline.



FIG. 94.

Photograph of an anticline near Hancock, W. Va.

stood by an examination of the accompanying figures. At times the folds are very regular (Fig. 94), but usually they are unsymmetrical (Fig. 95). They are generally ridge-

like, and in the direction of the ridge they gradually lose in size and finally disappear altogether. The direction in which these rocks enter the earth is known as the *dip*, while a horizontal line at right angles to this, is known as the *strike* (Figs. 92 and 93). If we considered one side of the gable roof of a house to represent an inclined layer of rock, the pitch of



FIG. 95.

Photograph of a fold in the rocks, Quebec, Canada.

to several thousand feet. In the latter case the movement did not all take place at once, but was the result of numerous slippings, perhaps continued for a long period of time. It is probable that in some mountain regions the rocks are even now being faulted; and in some cases the signs of present movement can be seen, particularly after earthquake shocks (Fig. 247).

Volcanic Action. — In many parts of the world, particularly in some of the higher mountains, molten rock and fragments of rock are reaching the surface through openings that pass down into the earth, probably to a depth of several miles. Usually these ejected materials build a cone which we know as a volcano (Fig. 234). The *molten* rock flows down the side of the cone as a *lava flow* and solidifies into rock. The *fragments* are usually porous like ash, and in large measure this *volcanic ash* or *pumice* also collects near the outlet of the volcano. Some volcanoes send forth one of these and some the other, while most eject now one and now the other.

Some of the volcanic eruptions are very violent, while others are quite gentle, and at times the ash is sent to great distances in the air. The lava flows often extend to a distance of many miles, deluging the surface over great areas. In some cases the lava comes to the surface through great cracks, flooding thousands of square miles of country. In earlier geological ages volcanoes existed in parts of the world where they are now absent, and in such places we sometimes find the lava flows at present on the surface.

Not only are these molten materials sent to the *surface*, but they are found to be *intruded* in many rocks. Since the lava comes from below, it must pass through the strata of the crust, and in many cases it solidifies there as injections. The tube, through which the lava passes on its way to the

crater of the volcano, becomes filled with solid lava when the volcanic action ceases; and sometimes it tries to reach the surface along other planes, breaking the rock open and filling the cracks with lava, forming *dikes* (Fig. 98). These are very abundant in regions of volcanic action, and they often occur in places where such action was once present, being the roots of old volcanoes. Such dikes are extremely

abundant in New England, where they may be seen in great numbers cutting across the rocks of the seashore.



FIG. 98.

Photograph of a dike crossing granite,
Cape Ann, Mass.

In some of the deep parts of the earth, in the center of mountains, these intruded masses are of great size, sometimes miles in diameter. These great *bosses* of intruded materials are illustrated by the granite areas; for these rocks were formed in this way, and are now exposed at the surface because the mountain cover has been worn

away. These great masses of molten rock, intruded into parts of the earth at depths of a few thousand feet, bring to these parts of the crust a greater heat than belongs there, and cause many peculiar changes.

Rocks of the Earth's Crust. — We have no means of knowing the condition of the earth at depths greater than a few thousand feet; but the rocks at the very surface are quite well known. There are three great groups of such

rocks, known as igneous, metamorphic, and sedimentary. The former come from within the earth, and reach their places in the crust as molten rock ; the second kind includes those which have been changed or metamorphosed, often by heat. This heat has been derived either from intruded volcanic rocks, or from friction accompanying the folding of mountains. The third group includes those rocks which were formed in water, mostly in the ocean.

Igneous Rocks. — When the igneous rocks come from below they are molten, and the elements of which they are composed are not definitely united to form minerals. As they cool, the elements tend to unite to form definite compounds, which are *minerals*. Such rocks are therefore *crystalline*, for they are composed of crystalline minerals. Since the chemical composition of the lavas varies in different places, there is much difference in the rock that is formed. Some are black, like the trap of the Palisades of the Hudson, or like the basaltic lava of the volcanoes of the Sandwich Islands, while others are nearly white. The minerals that are most common in these rocks, are quartz, feldspar, hornblende, and mica.¹

If a saturated solution of salt in hot water be allowed to cool suddenly, the salt forms one mass of small crystals ; but if several hours be allowed to elapse in the cooling, the crystals are much larger. Just so in these igneous rocks ; and as a result of this, some lavas are of very fine grain, and even glassy (known as obsidian or natural glass), while others are moderately coarse, and still others *very* coarse. Ordinary lava is fine grained because it cools rapidly at the surface, while the intruded rocks, such as granite, are much

¹ It does not seem profitable to describe these minerals or the rocks. If the students are not already familiar with them, it would be well to have them study specimens ; but mere descriptions are of little avail.

coarser, because they could not cool so rapidly. Therefore igneous rocks vary in two ways, in coarseness and in chemical composition, and hence in mineral constitution. All of these varieties are given names, but their study belongs to geology.

Metamorphic Rocks. — Though they were not molten, metamorphic rocks resemble the igneous in the fact that they are formed through the partial agency of heat, and in the fact that they are crystalline. They are the least important group, but in some places, such as New England and Canada, they are the most common of rocks. They are usually banded or foliated, and these bands are often greatly contorted (Fig. 99). Some of



FIG. 99.
Contorted limestone.

them are known to be the altered forms of other rocks, while the original condition of others cannot be told. We know that marble is the altered form of limestone, slate is metamorphosed from a clay rock, etc.; but the two most common metamorphic rocks — gneiss and schist — cannot usually be traced to their original condition. They are generally very hard rocks.

Sedimentary Rocks. — The most important of the groups is that of the sedimentary rocks, which are mostly sediments formed in the ocean. They may be divided into three classes, — mechanical, chemical, and organic. The organic rocks are formed from the remains of animals or plants, the coal illustrating the latter and limestone the former. The great ocean deposit of *Globigerina* ooze (page 164), and the coral reefs, are organic sediments. Chemical sediments

are not of sufficient importance to occupy space here, but the most important group is the mechanical.

The rocks of the earth's surface are being destroyed by various means, and the fragments are being transported toward the sea. Since some of the minerals cannot withstand the action of the weather, the rocks actually decay and form fragments; and as they change and crumble, the rock falls to pieces, thus making the beginning of a soil. Every rain takes some of these pulverized rock particles and carries them to a stream, where they begin their journey to the sea (Fig. 122). To these are added others which the stream takes from its bed; and in the ocean there are added those that the waves rasp from the land. In the ocean these accumulate in layers, the coarsest where the waters are in most rapid motion, and the finest where they are so still that



FIG. 100.

Stratified shale rocks in a gorge near Ithaca, N.Y.

the particles may settle. The coarser rocks with pebbles, such as those of the beaches, are known as conglomerates; the very finest produce clay rocks, such as the shales; and the intermediate sandstones are composed of sandy grains of the very durable mineral quartz.

Deposition of Sedimentary Rocks. — Reaching the ocean, these rock fragments are strewn over the bottom of the sea,

particularly near the coast, because here the ocean waters are so quiet that the particles must settle. In quiet bays, very fine-grained rocks may be deposited close to the shore ; but on more exposed coasts, the sediments of the shore line are



FIG. 101.

Section showing alternation of strata.

coarse-grained, and as the distance from the coast increases, they become finer in texture. Since the ocean bottom is usually nearly level, these fragments are spread out in layers which are nearly horizontal, though where the bottom is inclined, the layers are inclined with it. Sometimes the supply of sediment varies, either in amount or in kind, and so one layer may be deposited on another ; and this gives the *stratification* that is so characteristic of most sedimentary rocks (Fig. 100). We may have a layer or *stratum* of sand resting on one of clay, and upon this a layer of limestone, etc. (Fig. 101).

Sedimentary rocks are now being formed over the entire floor of the ocean ; but at a greater distance than a few score of miles from the land, the sediments for the most part are organic. The greater part of the rocks of the land are sedimentary in origin ; and most of them furnish evidence that they were formed in the ocean near the shore. This proves that they must have been elevated from the sea ; and we know full well that the continents are largely built of materials that were formed in the ocean not far from the shore. Sometimes these rocks have a thickness of thousands of feet, and yet they are made up of sediments that

were laid down in the shallow waters near the coast. The only way in which this could happen is by a continued sinking of the bottom. Therefore the sedimentary rocks teach us that parts of the sea bottom continued to sink for a long time, and were then elevated to form continents.

Other movements of the crust are also shown by some of these rocks. At times there are *unconformities* (Figs. 102 and 103): that is, rocks made in the sea, rest on other sea-

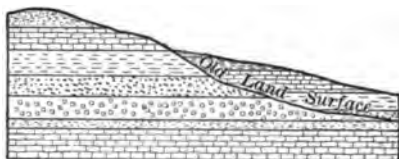


FIG. 102.

An unconformity in horizontal rocks.

formed strata which were deposited at an earlier period, and have since been land. Thus we have in these cases, (1) deposit in the ocean, (2) elevation to land, (3) depression beneath the sea, and (4) a second elevation. In some cases there are numerous such unconformities, showing successive changes. These, and other facts, prove that the crust of the

earth is almost constantly in movement.

Consolidation of Sedimentary Rocks.

— The rocks of the sea are soft and unconsolidated, while those of the land are generally hard and

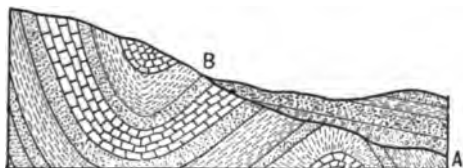


FIG. 103.

An unconformity in inclined rocks. A, B, old land surface.

compact. The consolidation of rocks is a simple process, generally resulting from heat, pressure, the deposition of some cement, or a combination of several such causes. In a hydraulic press we can consolidate clay; and in a similar way, the great weight of the strata of the crust, furnishes the necessary pressure for the natural consolidation of rocks.

Bricks are consolidated by heat, and in the earth heat often acts in a similar manner. All rocks in the earth are filled with water which is slowly percolating through them. This water is dissolving substances from one place and depositing them in others, and in this way many rocks are being consolidated. Carbonate of lime and some compound of iron, are the common rock cements; and these, perhaps aided by one of the other causes, bind the rock particles together.

Geological Chronology. — By a study of the rocks, the main facts of geological history have been determined in a more or less satisfactory manner. We know something of the history of the globe, and the rocks form the pages and chapters of this history. The rock record is often very imperfect. Some pages, and at times entire chapters, are missing; but enough still remains to furnish a basis of value. One thing shown, is that the world is very old, and that no statement of the history in years or centuries is possible. Therefore there is no chronology of the kind that we are accustomed to use in recording human events.

In many of the sedimentary rocks there are fossils, which are the entombed remnants of animals and plants that lived when these rocks were formed (Fig. 104). If 1000 feet of rocks are found, one laid down upon the other, and if these contain fossils, there is preserved a record of some of the organisms that lived while these rocks were being deposited. By a very careful study of the fossils of various parts of the earth, a nearly continuous record of the life of the globe has been obtained, from near the beginning of life to the present time. It is found that in the lowest rocks — that is, in the oldest — the animal remains are only of low types. At first there were no land animals and plants; and in the sea, the only animals were of types lower than the true fishes. The fishes appeared, then reptiles, birds, and mam-

mals in succession; and this evolution from lower to higher forms is noticed even among the subdivisions of life.

Therefore, upon examining the fossils from a rock, a geologist can tell in what part of the earth's history they lived, and to what stage in this history the rock belongs. It is like the study of prehistoric man, which is based on the implements he used. Certain kinds of stone implements

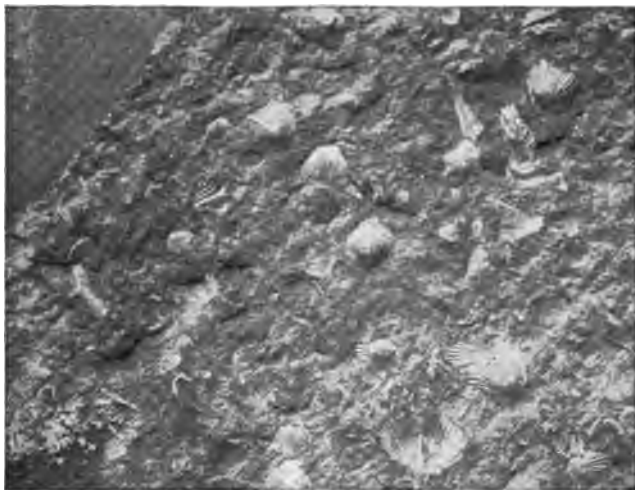


FIG. 104.

Photograph of a rock containing fossils.

mark the palæolithic age, others the neolithic; bronze implements mark a higher stage, etc. This does not mean an age in any sense in which years are used, but rather a *stage*. One of these stages may represent a thousand years, another several thousand; but each one represents a stage different from that which preceded and succeeded.

So it is with the geological chronology. We have absolutely no basis for division into periods of years; but we can

divide the history into stages, each stage representing some advance in the development of life on the globe. For this purpose, names are used to signify the stages, as is indicated in the table below, which is a simple one from which the

TABLE OF GEOLOGICAL AGES.

CENOZOIC TIME. Age of <u>mammals</u> .	<i>Quaternary.</i>	Man assumes importance, particularly in the upper part. In the first half the Glacial Period prevailed.
	<i>Tertiary.</i>	Mammals develop in remarkable variety, and to great size, while reptiles diminish.
MESOZOIC TIME. Age of <u>reptiles</u> .	<i>Cretaceous.</i>	Birds begin to become important, reptiles continue, and higher mammals begin. Land plants and insects of high types.
	<i>Jurassic.</i>	Reptiles and amphibia continue to be predominant.
	<i>Triassic.</i>	Amphibia and reptiles develop remarkably. Mammals of low forms appear.
PALÆOZOIC TIME. The age of <u>invertebrates</u> .	<i>Carboniferous.</i>	Land plants assume great importance.
	<i>Devonian.</i>	Fishes begin to be abundant.
	<i>Silurian.</i>	Invertebrates prevail. ¹
	<i>Cambrian.</i>	No forms higher than invertebrates.
In part AZOIC TIME. No fossils known	<i>Archean.</i>	Mostly metamorphic rocks, perhaps in part the original crust of the earth.

¹ Invertebrates of course continue down to the very present; but until the Devonian, they were the most important group. The same is true of fishes, which begin to be abundant in the Devonian, but continue down to the present.

subdivisions are omitted. Each of these ages represents the lapse of immense periods of time, perhaps hundreds of thousands of years ; but no interpretation of years is to be placed upon them, nor should it be assumed that they are of equal length. The Carboniferous represents the stage in the earth's history when plants had reached a certain type of development upon the land, etc.

Age of the Earth. — As has been said, we have no basis for an estimate of the age of the earth. By some scientists estimates have been made upon one basis or another, and these have ranged between 3,000,000 and 2,400,000,000 years, though the majority have estimated a few hundred million years. Since these estimates were made by very different men, upon entirely different facts, they have the one great value that they prove the great age of the earth.

One cannot go far in the study of geology without being convinced by the overwhelming evidence that the earth is exceedingly old. To attempt to explain the phenomena of the earth's surface upon the basis of single years or centuries, would be as fruitless as would be the attempt of the astronomer to explain the facts of the solar system on the supposition that the planets were at distances of a few thousand miles. The only way to have the force of this statement impressed in all of its fulness, is to study the earth with the eyes of a geologist ; and in a study of this nature only the beginning of this can be attempted. Still it is necessary that this fact should be accepted at the outset. Just as the student of astronomy gazes at the stars, and, upon faith alone, accepts the statement that these bodies lie millions and even billions of miles from him, so the student of geology or physical geography must commence the study of the earth with the belief that the history which it has passed through has occupied not years, nor thousands, nor

even hundreds of thousands, but millions and probably hundreds of millions of years. The evidence is overwhelming, and no geologist finds reason to doubt it.

The gorge of Niagara, 200 or 300 feet deep, and 7 miles long, has taken not far from 10,000 years for its formation; how much longer was the time occupied in forming the cañon of the Colorado, whose length is 300 miles, and whose depth in places is over a mile! Yet these were formed in late stages in the development of the continent.

We watch a volcano for a century, and, at the end of that time, find its general form to be the same as at the beginning; yet most of the volcanic cones of the world were begun not earlier than the commencement of the Tertiary. Studying the rate of deposit of the sedimentary rocks of the ocean, we find that, even when the deposit is rapidly made, but a few feet are laid down in a single century; yet, in some places, many thousand feet of rocks have thus been deposited, one layer upon another. In the Appalachian Mountains there are fully 40,000 feet of these strata, and they were all formed in the Palæozoic. How many scores of centuries do these represent!

This, and other evidence equally striking, is what has driven the geologists to the conclusion (for a long time opposed, as was the present astronomy when first proposed) that the age of the earth is incalculable, but great,—a conclusion now quite universally accepted. It is the basal conception of geology, and must be accepted at the beginning. To it must be added the conception of the fact that the earth is changing. These changes, so slow as to be almost imperceptible in a single lifetime, when allowed long periods of time for their action, will produce the most profound and stupendous revolutions. From this time on we will study the crust of the earth as a thing of constant change, and of great, but

indefinite age. The present is but one stage in its history: there has been a past, and there will be a future, just as is the case with the history of man himself.

REFERENCE BOOKS.

LARGER BOOKS OF REFERENCE.

- Geikie.**—**TEXT BOOK OF GEOLOGY.** Macmillan & Co., New York. Third edition (revised), 1893. 8vo. \$7.50. (The most complete English text book.)
- Dana.**—**MANUAL OF GEOLOGY.** American Book Co., New York. Fourth edition (revised), 1895. 8vo. \$5.00. (The standard American reference book; thoroughly revised to date.)
- Le Conte.**—**ELEMENTS OF GEOLOGY.** American Book Co., New York. Revised edition, 1891. 8vo. \$4.00. (A very valuable book of reference.)

SMALLER TEXT BOOKS.

- Geikie.**—**CLASS BOOK OF GEOLOGY.** Macmillan & Co., New York. Third edition, 1892. 12mo. \$1.10.
- Jukes-Browne.**—**HANDBOOK OF PHYSICAL GEOLOGY.** Macmillan & Co., New York. Second edition, 1892. 12mo. \$1.75.
- Le Conte.**—**COMPEND OF GEOLOGY.** American Book Co., New York, 1894. 12mo. \$1.20.
- Dana.**—**TEXT BOOK OF GEOLOGY.** American Book Co., New York. Fourth edition, 1884. 8vo. \$2.00.
- Winchell.**—**GEOLOGICAL STUDIES.** Griggs, Chicago. Fourth edition, 1892. 12mo. \$2.50.

This list contains only a few of the many excellent text books of geology; and others are referred to at the end of the next chapter.

In some of the states of the Union, there are geological surveys which have published reports in which one may often find a description of his own region. Among others, the following states have recently had such surveys: New York, New Jersey, Pennsylvania, North Carolina, Georgia, Alabama, Mississippi, Texas, Arkansas, Ohio, Michigan, Minnesota, Missouri, Kansas, Iowa, South Dakota, and California. Where the reports cannot be obtained from the state geologist, they can often be found in second-hand stores.

CHAPTER XIII.

DENUDATION OF THE LAND.

Underground Water. — When rocks are deposited in the ocean, the crevices between the particles of sediment are filled with water. In even the densest of rocks there are cavities, and through all of these, water is slowly percolating as underground water. Added to the supply originally in the rocks, there is a constant body of water entering at the surface. When rain falls upon the land, a part is returned to the air by evaporation, a second portion flows away as surface water, and a third part sinks into the ground. This last portion commences an underground journey through the strata, in the course of which much work is done. It moves along the larger crevices, and also slowly passes through the very rock itself. That this water is actually present in the strata, is shown by the fact that wells may be constructed in them; and even in the deepest mines, water is found to be present in the rocks.

Some minerals are soluble in water, and the hardness of certain waters is due to the fact that they contain mineral matter in solution. All underground water is engaged in this work of *dissolving rock materials*. While pure water has but little power of solution for ordinary minerals, when it is supplied with certain impurities its solvent power is greatly increased. There are many substances which add power to this percolating water, but those which are most commonly present, are the various acids supplied by decaying

vegetation. The humous and humic acids and carbonic acid gas are most commonly present in underground water; and armed with these, it possesses great solvent power. When the water has percolated to a considerable depth in the earth, its temperature is so raised that its power is greatly increased. In some cases it obtains a temperature higher than the boiling point at the surface; and then it becomes a powerful solvent, particularly if it is armed with acids or alkalies. When it reaches the surface in the form of a spring, we very often find proof that underground water is engaged in this work of solution. Many of these are mineral springs, and at times, *deposits* of iron, or other substances, are



FIG. 105.

Deposits of carbonate of lime, Pulpit terrace, Mammoth Hot Springs of Yellowstone Park.

made where the water reaches the surface. When hot water escapes at the surface, as is the case in the geyser region of the Yellowstone Park, extensive chemical deposits of rock are sometimes formed around the springs (Fig.105). The reason for the deposit of these substances, is sometimes that the temperature of the water is lowered, and its solvent power thereby decreased; in other cases it is due to the

escape of certain gases which gave to it much of its power ; and it is often the result of chemical changes in the presence of the air. Even in the earth, for one reason or another, the water at times deposits some of its dissolved load. This is one of the ways in which rocks are cemented ; and it appears to be one of the causes for the formation of some of the valuable mineral deposits.

Underground water is also engaged in the work of *changing* some of the minerals of the rocks. It actually causes a decay of some minerals, and brings about very important changes in others. This is one of the ways in which the rocks are broken into fragments, and soils formed. This



FIG. 106.

Diagram to illustrate the formation of caverns.

work of underground water is not confined to the surface layers, but extends to considerable depths in the earth. However, from our present standpoint, the most important changes are those which are produced nearly at the surface, and these are again referred to below.

The Formation of Caverns. — Limestone is one of the most soluble of the rocks ; and in many of the regions where this exists, the solvent action of underground water goes so far as to actually dissolve cavities in the strata (Fig. 106). It sinks into the ground through depressions, or sink holes (Fig. 107), and passes along planes of weakness, which it enlarges by solution ; and in some cases, this underground water assumes the form of true subterranean rivers, which

are sometimes several miles in length. The *caverns* (Fig. 106) thus formed, are very irregular; and some, such as the Mammoth Cave of Kentucky, and Luray Cave, have been explored and opened to tourists; but there are thousands which have never been



FIG. 107. A sink hole in a limestone region.



FIG. 108. Stalactites in cavern of Luray.

entered. In some of these caves, the water that percolates through the roof, deposits columns and pendants of carbonate of lime, which often produce most beautiful effects. When these reach from the roof they are known as *stalactites* (Fig. 108); and when they extend from the floor, they are called *stalagmites*; while by the junction of these, *columns* are often formed from floor to

roof. They are formed because on entering the cave the water loses some of the carbonic acid gas which gave to it its solvent powers, and thereby has its ability to hold in solution decreased. By the gradual lowering of the land, the roofs of these caverns are sometimes destroyed, and the streams that occupy them are changed to surface rivers. Where a part of the roof remains, a *natural bridge* is sometimes formed (Figs. 106 and 109).



FIG. 109.

The Natural Bridge, Virginia.

Springs and Artesian Wells. — Underground water often finds channels of escape to the surface; and where it reaches the surface, springs are produced. This escape may be along fault planes, or other breaks in the rocks (Fig. 110), or it may be at the outlet of a subterranean stream which passes through a cavern (Fig. 131); but the majority of springs occur where a

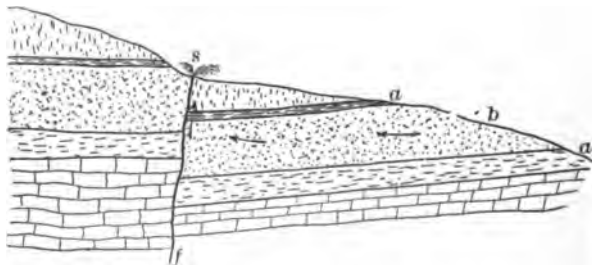


FIG. 110.

A spring formed along a fault plane (*f, s*); (*a, a*) impervious layers; (*b*) porous stratum. Arrows show the course followed by the underground water leading to the spring (*a*). Water passes up the fault plane from *f* to *s*.

loose-textured rock rests upon a less permeable one, and where this junction is exposed at the surface (Fig. 111).

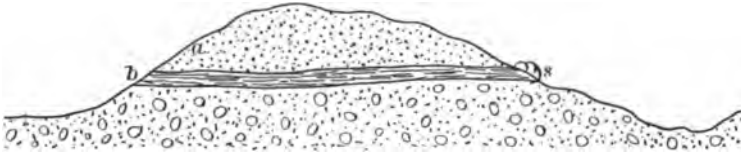


FIG. 111.

Hillside spring (*s*) at junction of permeable layer (*a*) and impervious layer (*b*).

This is particularly liable to happen on hillsides where a layer of sand rests upon a stratum of clay.

In the earth, certain strata are more permeable to water than are others; and under some circumstances the conditions favoring the production of *artesian wells* (Fig. 112) may be present. Sandstones are the most permeable of rocks, and when a sandy layer crops out at the surface, the water readily soaks into it. If such a layer is covered and underlaid by a more dense rock, such as a clay stratum, the water that enters the sandy layer is in large measure imprisoned within it. If under such conditions the strata dip into the earth, the water in the sandstone passes down this layer between the two enclosing walls. As a result of the weight of the column of water in the stratum, it is under a considerable



FIG. 112.
Artesian well.

pressure; and this is sufficient to force it upward toward the surface, to a height nearly as great as that of the place where the water enters the ground.

If this water-bearing layer is pierced by a well-boring, the water will rise in the well as high as the pressure can force it; and if the place at which the well is bored,

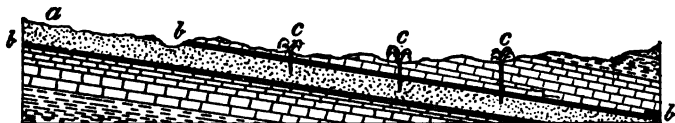


FIG. 113.

Conditions favoring artesian wells (c, c, c), where the rocks are inclined in a single direction. Porous sandy layer (a), impervious strata (b, b).

has a lower elevation than the water head, the water from the stratum may reach the surface as a fountain, forming an artesian well (Fig. 113). When this condition is encountered in a syncline, there are two water heads, and this greatly favors the formation of an artesian well (Fig. 114).



FIG. 114.

Artesian wells (c, c, c), where rocks are folded into the form of a syncline; (a, a) porous layer between two impervious layers (b, b).

In eastern Texas, there is a water-bearing stratum extending over a great area (Fig. 113), which has been tapped at numerous places, and which furnishes abundant water supply for several cities; and the same is true of South Dakota and elsewhere. In many parts of the west, artesian wells are very useful for purposes of irrigation. It often happens

that the water does not rise quite to the surface, and then pumps are necessary, the pumping often being done by wind-mills.

Durability of Rocks. — There is a great difference in the ability of rocks to withstand the action of the agents which are tending to destroy them. Some, such as granites, are very hard; others, such as limestones and shales, are soft.

Many rocks that are *hard* are chemically weak, and their minerals are easily dissolved, or are readily altered. By these processes, such strata are caused to decay and crumble. Some rocks are loose in texture and readily entered by percolating water, while others are dense and quite impermeable. Other things being equal, the latter are less easily destroyed than those that are loose in texture. Some which are mechanically hard are readily destroyed by chemical means. In the later pages, when a

hard rock is mentioned, the term is used not merely in the mechanical sense, but as a synonym of resistant.¹ All rocks, no matter how resistant they may be, are capable of being



FIG. 115.

Rock pillars, Garden of Gods, Colorado.
Soft rock capped by a harder one and
hence protected from destruction.

¹ That is to say, a hard or resistant rock is one which withstands all attacks, whether mechanical or chemical, more successfully than less durable rocks, as explained in the next section.



PLATE 20.

Earth columns, New Mexico. Illustrating the greater resistance of the thin, hard layers in soft clay. The beginning of the formation of rock pillars.

destroyed ; but there is a difference in their power of resisting destruction (Fig. 115 and Plate 20).

Weathering. — When exposed to the air, or to the weather, rocks are destroyed by various agents which may be included under the general heading of weathering. These agents are both chemical and mechanical. Already some of the *chemical changes* have been noted in the section on underground water. Soluble minerals are taken from the rocks, and those that are left are then less firmly bound together. The same result is



FIG. 116.

The crumbling of granite by disintegration of the minerals.

brought about by the change of minerals during the passage of water through them. Usually the change leaves the rock less firm than it was at first, and it often produces a clayey product in the place of the firm mineral that was originally present. These chemical changes are particularly liable to happen in the crystalline rocks, which were formed by the aid of heat (Fig. 116). When exposed to the air and water, the minerals that cooled from a molten condition are found to be unstable and liable to change. Some minerals, such as quartz, resist this destruction, and this is why we have fresh

quartz grains in sandstones that have been produced by the decay of rocks in which quartz was one constituent. The clay of such rocks as shale is mostly the product of this rock decay. Another result of these changes is to furnish dissolved mineral substances to river water, and hence to the sea.

Of the *mechanical agents*, perhaps the most important is that of *change in temperature*, which, however, affects only the very surface rocks. In the regions which experience great temperature ranges, the rocks become warmed during the day and cooled at night. This introduces an alternate expansion and contraction, which causes fragments to be split from the rock surface. If the temperature descends below the freezing point, as is the case in the high temperate and arctic latitudes, the water in the rock crevices is frozen, and, by the consequent expansion, fragments are pried off. This is a very important action on mountain tops (Fig. 224) and on exposed ledges in cold countries. A snow covering tends to check this action. Naturally, those rocks with porous texture are more open to the attacks of frost than those which are compact; and open-textured rocks are also more liable to be readily destroyed by percolating water than are those of fine and compact grain.

Plants are also important agents of weathering, and their action is both chemical and mechanical. They act chemically by furnishing to percolating water many of the substances with which it is able to dissolve and alter the minerals; and they also extract mineral matter from the soil in water absorbed through the roots. The mechanical action of plants is mainly that of their roots. These enter the rock crevices, and upon growing, enlarge these cavities, causing the rocks to crumble (Fig. 117). This action may often be seen upon a ledge on which lichens are

growing; and the roots of trees are doing a very important work of this nature, because they extend through the soil to the rock beneath.

Even *animals* are aiding in this work, particularly those that burrow in the earth. Earthworms are of great importance in this respect, for they are engaged in the constant work of pulverizing the soil. The action of the agents above described, is not confined to the solid rock, but it is



FIG. 117.

Roots of a tree breaking a rock into fragments.

constantly in progress in the soil, the tendency always being to make this finer in texture.

The results of this action of weathering are most widespread. All over the land, in nearly every place, the rocks are being destroyed by these agents; and weathering is the most important single cause for the destruction of the strata and the melting down of the surface of the land. Weathering is more rapid in some places than in others. On the cold mountain tops, its action is rapid (Fig. 224), as it is also in regions of moisture. On the other hand, in arid regions where rain is uncommon, weathering is relatively slow, as

it is also in regions where a deep soil covering protects the rocks. Upon exposed ledges, weathering is rapid ; and this is particularly true of cliffs, where the fragments drop to the base in the form of a talus (Figs. 118, 122), leaving the rock-face bare to future attacks. Then also, weathering is more rapid in some kinds of rocks than in others.



FIG. 118.

Talus, valley of Rio Grande, New Mexico.

The great result of weathering is the lowering of the land surface ; and in the course of the vast ages of geological time, not only hills, but mountains and volcanoes, have been destroyed mainly by the action of this slow melting away of the rocks. By the folding and elevation of the strata, new tasks are constantly set before these agents, and we may

say that there are two opposing forces at work, one tending to increase land elevations, the other to lower them. In this combat, elevation has excelled ; and as a result we have a very irregular land surface. If there had been no weathering, the land elevation would have been vastly greater, but the surface of the land would have been much more regular. If there had been but one elevation, and that at the beginning, the land would have been worn down to a nearly level plain.

Had weathering been the only agent of destruction, the result would have been very different. With nothing to remove the fragments, the solid rock would have been covered with a soil that would have protected the



FIG. 119.

Disintegrated rock, forming residual soil.

strata from further destruction ; and the longer it acted, the less its power would be, the process being, as it were, self-destructive. There *have* been other agents at work, and these have served to remove the disintegrated rock fragments. Some of these agents, being chemical, have carried the material away in solution, others have acted mechanically. These are described under the following heading of erosion.

Among the results of weathering, one of prime importance

to man is the formation of *soil*. In many parts of the earth the soil is the result of rock disintegration (Fig. 119); and in some places, particularly in the tropics, this *residual soil* (so called because it is largely composed of the insoluble residue of rock decay) has a depth of 100 or 200 feet. In this country it is of particular importance in the Southern States, the soil of the Northern States being largely the result of glacial action, and being a transported soil. Another



FIG. 120.
Sand dunes, Cape Ann, Mass.

important effect of this rock decay, is that it furnishes to rivers the larger part of the sediment load with which they are able to cut their channels, the rock particles being used as cutting tools.

Agents of Erosion.

— In certain places, various agents are at work cutting into the rocks and re-

moving materials, either chemically, mechanically, or both. The most important of these are wind, rain, percolating water, rivers, oceans, and glaciers.

Wind Erosion. — In some places the action of the wind is of considerable importance; but in most regions a forest or grass covering protects the rock and soil from its action. On the seashore the blowing of the wind drives sand about, and with it often batters the rocks in a manner analogous to the sand blast with which glass is ground. On some of the sandy islands of the seacoast, the window panes are some-

times transformed to ground glass. Many narrow islands along the seashore are built above sea level by the action of the wind upon the sand, which is washed into the form of bars by the waves; and on some coasts this sand is driven inland, where it accumulates as hills, known as sand dunes (Fig. 120). In the arid regions, where the soil is not covered with dense vegetation (Fig. 121), the winds are constantly engaged in the removal of the finer rock fragments; and in these places the wind becomes one of the most important agents of erosion. Oftentimes the air is filled with blown sand, so that even neighboring hills are obscured. This natural sand blast beats against the rocks, and wears them away, removing all the finer particles as fast as they fall from the rocks (Figs. 69 and 121).



FIG. 121.

Moqui Pueblo, New Mexico, a rocky point exposed to wind action.

Rain Erosion. — During a rain, the drops that reach the soil do a slight amount of erosion and transportation, particularly if they fall upon a hillside. Even before the rain gathers into little rills, it does some work of this kind; and when it has formed tiny streams, it commences to wash the soil down toward the rivers. This is one of the ways in which rivers are supplied with their load of sediment. During a rain, one may see this process upon a plowed field or on a road. In the forest, and upon turf-covered land, this action of the rain is of little importance; but in dry regions, where the soil is not protected, every rain causes the soil to creep down the hillsides; and in the mountains of the arid regions, great gravel-slopes are by this means accumulated at

the mountain bases. This form of erosion merges into that of rivers. In some places (Plates 20, 21, and 29) rain erosion has carved the soft clay of the arid lands into a series of fantastic and remarkable forms.

Gravity is an important factor in this and other kinds of erosion; but even when unaided by any of the agents of



FIG. 122.

River receiving the load from a talus at the base of a cañon wall.

erosion, gravity alone is in some places an agent of destruction. The fragments loosened from cliffs by frost, or other agents of weathering, fall to their base and accumulate there as talus slopes (Figs. 118, 122, and 219). This is an important source of sediment for rivers, and among mountains, the talus slopes are important elements in the topography.

Percolating Water. — A second part of the rain enters the

ground; and aside from the work of rock destruction described above, it does an important work of rock removal. This is largely chemical, but partly mechanical. It removes soluble substances; and when it again reaches the surface, some, if not all of this, is furnished to streams for transportation, and thus much of it finds its way to the sea.

The most important mechanical work, is that of aiding the sliding of the soil down the hill slopes. The percolating water makes the soil particles slippery, and in some cases great masses fall down, forming *avalanches* or *landslides*. These very frequently occur where a porous layer rests upon an impervious one, as for instance when a sand stratum rests upon a layer of clay. The clay is lubricated and a slipping plane produced; and then under favorable circumstances, a mass of earth falls down. A strong wind blowing through the trees may start the slide, or the action of frost, or of a heavy rain, may introduce the conditions which are necessary for the beginning of the landslide.

River Erosion. — The subject of rivers is taken up in the next chapter, and only a few words need to be given to it here. The river is engaged in three great tasks, (1) the removal of water from the land, (2) the transportation of sediment given to it, and (3) the cutting of its channel. Two kinds of material are furnished to it, (1) mineral matter in solution, largely supplied by the underground water which is tributary to the stream, and (2) fragments of rock furnished by weathering. Under different circumstances, the amounts of these substances vary greatly. Some streams are clear and free from sediment, others are always filled with mud; but most streams are usually clear, and become clouded with sediment only after a heavy rain. In some cases, the material carried is in the form of fine mud; in others it is pebbles and even large boulders (Fig. 124). All streams

carry substances in solution, but some have a little, while others carry great quantities; and in desert regions, the rivers are sometimes so full of dissolved substances, that the water tastes bitter or salt.

Armed with its load of sediment, the river cuts the rocks of its channel, and deepens its valley; and by swinging from



FIG. 123.

Yellowstone Valley, showing the broadening of a V-shaped valley by weathering.

one side to the other, it broadens the valley slightly. Thus by river erosion, there is produced a relatively deep and narrow channel, a gorge, or a cañon. In arid regions, where weathering is of little importance, this is the prevailing type of river valley; but most of the valleys of moist countries are U-shaped rather than V-

shaped. This is because the action of weathering has caused the valley sides to melt back. River erosion deepens, weathering broadens the valleys (Fig. 123); and since the latter acts more slowly than the former, when streams *begin* their work, they produce deep, narrow valleys, even in moist countries. They cut down much more rapidly than weathering can broaden, and hence young valleys are gorges; and this is true wherever erosion greatly exceeds weathering.

The rate of erosion varies with the slope and the volume of water in the stream. Where the slope is great, if other conditions are favorable, the erosion is rapid; and where the amount of water is great, the erosion is more rapid than under similar circumstances with smaller volume. Therefore in the same stream, the amount of erosion done during its swollen condition, greatly exceeds that done when the amount of water is not great (Fig. 124).



FIG. 124.

Westfield River, Massachusetts, showing boulders which may be moved when the river is swollen.

The rate also varies with the amount of sediment; for if there is no sediment, there are no tools with which to work, and clear water can do little work except that of solution, which is relatively unimportant. On the other hand, if the river is given more sediment than it can dispose of, it cannot cut its channel, but must deposit some of its load in the valley, as is being done in the lower Mississippi. The most favorable condition is that of a moderate amount of

sediment. With the hardness of the rocks there is also a variation; for a river cannot cut its channel so rapidly in a hard granite as it can in a soft clay.

From this it will be seen, that the rate and kind of work that a stream is doing, varies greatly according to circumstances; and it follows that river valleys must present very different characteristics. Some are narrow, others broad; some deep, others shallow; some have rapid slope, others have a gentle flow, etc. In carving the land, river erosion



FIG. 125.

An oceanic volcanic island, showing a cliff produced by wave action in eating back into the land.

is an important agent; but its importance does not depend so much upon the work of cutting it does, as upon the fact that it is the agency by which rock fragments, prepared by other means, are removed from the land. River erosion and weathering are intimately combined in the destruction of the land, and in the sculpturing of its surface.

Ocean Erosion. — The action of the ocean in eroding, is confined to the limited area of the immediate coast line; but here it is often very important. The waves are constantly

beating on the shore, and battering at the rocks, often with terrific force. Armed with sand and pebbles, and even by its direct action, the wave is able to wear back even the hardest rocks; and in the ocean, islands that were once of great size are now only remnants (Figs. 125 and 195).

On the beaches and on the headlands, rocks are being ground into finer particles. The materials thus obtained, added to those received from other sources, are removed, mainly by the movements of the wind and tidal currents,



FIG. 126.

A granite hill rounded by glacial action.

and distributed over the bottom of the sea near the land. In these ways coasts are changed in form, and are ever changing; though here, as in most other geological changes, the work is slowly accomplished. On the British coast, where the changes have been studied for centuries, it is found that the coast line has been very decidedly altered by ocean erosion.

Glacial Erosion. — Glaciers are now relatively scarce in this country, but at one time they were present in northern United States (Chapter XVII.), and they then did considerable work of erosion. Because it is a rigid body, ice acts dif-

ferently from water. There is no chemical work done, and the mechanical work is different; for the ice exerts a great pressure, and, armed with rock fragments, it scours its bed in a manner analogous to a great sandpaper. It rounds off the surface (Fig. 126) and acts all over its bed, so that if it spreads over a country, it scours hills as well as valleys. Mountain glaciers move down the valleys, scouring their bottoms and sides, and transporting much rock material.

Denudation.—The combined action of these forces of weathering and erosion is denudation. In intimate relation they all act toward the one end of reducing the land; and in this respect they are in opposition to the great internal force which is causing the land to rise and fall. They owe their power mainly to forces from without the earth. The moon and sun produce the tides, the sun causes the changes in the weather, the atmosphere acts as the intermediary, the ocean furnishes the water, and two internal forces furnish the opportunity,—internal heat and gravity. The former gives elevations to be destroyed, the latter draws the water to the earth and causes a tendency for the materials to move from higher to lower places. Weathering is the great agency of preparation; for their chief work, the erosive agents do some destruction and much transportation; and the ocean, aside from its work of erosion, is the great receiving ground for the waste from the land.

These changes are in progress at all times, and they have been so through all of the geological ages, with the result that, although slowly acting, they have produced enormous changes. The present land forms are the result of the action of these forces (Plate 21 illustrates exceptionally rapid denudation); and since they are still acting as in the past, the surface of the earth is even now changing. The land is therefore in one stage of its history, and we must not look



PLATE 21.

Bad Lands, South Dakota. An instance of excessive sculpturing of soft rocks by the agents of denudation.

upon the hills and valleys as unchanging and unchangeable, but rather as things of life, with a past history to be read, and a future to be predicted.

REFERENCE BOOKS.

Aside from those to which reference has been made at the close of the preceding chapter :—

Lyell. — **PRINCIPLES OF GEOLOGY**, Vols. I. and II. Appleton & Co., New York. Eleventh edition, 1872. 8vo. \$8.00. (This is the great geological classic, especially complete on the subject of denudation.)

Shaler. — **FIRST BOOK IN GEOLOGY**. Heath & Co., Boston, 1884. 12mo. \$1.00. (This interesting little book is written for beginners.)

Shaler. — **ASPECTS OF THE EARTH**. Scribner, New York, 1889. 8vo. \$2.50. (Several chapters on topics touched upon in this and the preceding chapter.)

For **SOILS**, see article by Shaler, "Twelfth Annual Report U. S. Geological Survey." Washington, D.C., 1891.

For **ARTESIAN WELLS**, see article by Chamberlin in the Fifth Annual Report of the same, 1885.

For importance of **EARTHWORMS**, see Darwin, "The Formation of Vegetable Mould." Appleton & Co. (International Scientific Series), New York, 1883. 12mo. \$1.50.

One of the most important contributions to denudation is Gilbert's "Geology of the Henry Mountains," Washington, 1887. (To be obtained only from the second-hand bookstores.)

Many valuable and interesting papers appear in the regular geological periodicals, of which there are three issued in this country, as follows : (1) "Bulletin of the Geological Society of America." Six volumes already issued at \$5.00 (to libraries) a volume. Address Professor H. L. Fairchild, Rochester, New York. (2) "American Geologist," Minneapolis, Minnesota, now in its sixteenth volume, two being published each year. Price \$3.50 a year. (3) "Journal of Geology," Chicago, Illinois, now in its third volume. Price, \$3.00 a volume.

CHAPTER XIV.

TOPOGRAPHIC FEATURES OF THE EARTH'S SURFACE.

Continents and Ocean Basins. — The surface of the earth is broken by a series of great irregularities, forming the continents and the ocean basins. There are two groups of continents, with intermediate basins filled with water. The continent masses, which may be called the eastern and the western, are mainly grouped about the north pole, causing the northern to be the land hemisphere; and the oceans are gathered around the south pole, entirely surrounding it, and extending rather triangular tongues northward, toward the north pole. The two sets of continents are themselves more or less completely divided along nearly east and west lines. This division is north of the equator, and it is the cause for the separation of North and South America, and of Europe and Africa. With these partial or complete oceanic separations we have four great continent masses: North America, South America, Africa, and Eurasia. Australia, the fifth, is somewhat aberrant.

The oceans are developed into two great basins, the Atlantic and the Pacific, the latter having an area of fully 62,000,000 square miles, which is equal to nearly one-third of the area of the earth's surface. Besides these, there are the Arctic, Antarctic, and Indian oceans, which are only partially separated from the others. The Atlantic has an average breadth of a little less than 3000 miles, while the breadth of the Pacific is fully twice as great as this. And we find the

same difference in size between the eastern and the western group of continents. The American continents have an average breadth of but little more than 2000 miles, while the average breadth of Europe and Asia combined, is over 6000 miles.

As has been described in Chapter IX., the oceans for the most part consist of great submarine plains or plateaus, here and there broken by gently rising ridges, or occasionally by steeply rising volcanoes or sharp mountain ridges. The pre-



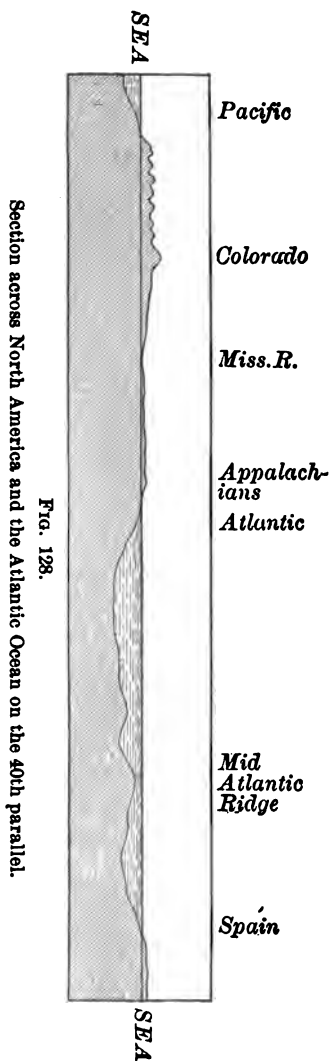
FIG. 127.

Relief map of Eurasia (Lambert's projection).

vailing feature of the ocean bottom is that of uniform levelness; and the average depth of this great submarine plateau is nearly three miles, while in some places the depth is over five miles. This great area, which is about three-fourths that of the earth's surface, is rendered level by means of the oceanic water which fills the basin. Above the ocean surface the continents rise with considerable uniformity, but their average elevation is very much less than the depth of the ocean. The average elevation of the land surface of the globe is

about 2000 feet; and it is only here and there, along mountain chains and plateaus, that greater elevations are found; but the average depth of the ocean is fully six times as much. This difference between land elevation and ocean depression, is shown in Fig. 128, which represents a cross-section of North America and the Atlantic Ocean, drawn upon the same vertical scale, which is greatly exaggerated.

Examining the continents in a little more detail, we find that they consist of plateaus and plains as the most prominent features. Usually there are two plateau areas, one upon either margin of the continent; and above these rise more or less continuous ridges, which we know as mountain chains. This feature of continents is well illustrated in North America (Fig. 129), which may be considered a typical continent; and it will be described in more detail in later parts of the chapter. Plains usually occupy the interior portion of the continent, and these are sometimes in the form of low plateaus; while



in some cases they are even interior basins. The land surface is very irregular, the irregularities being partly due to original features of the earth's crust, and partly to the sculpturing of these by the agents of denudation (see Chapter XIII.).

Geological conditions conclusively prove that the con-



FIG. 129.

Relief map of North America (Lambert's projection).

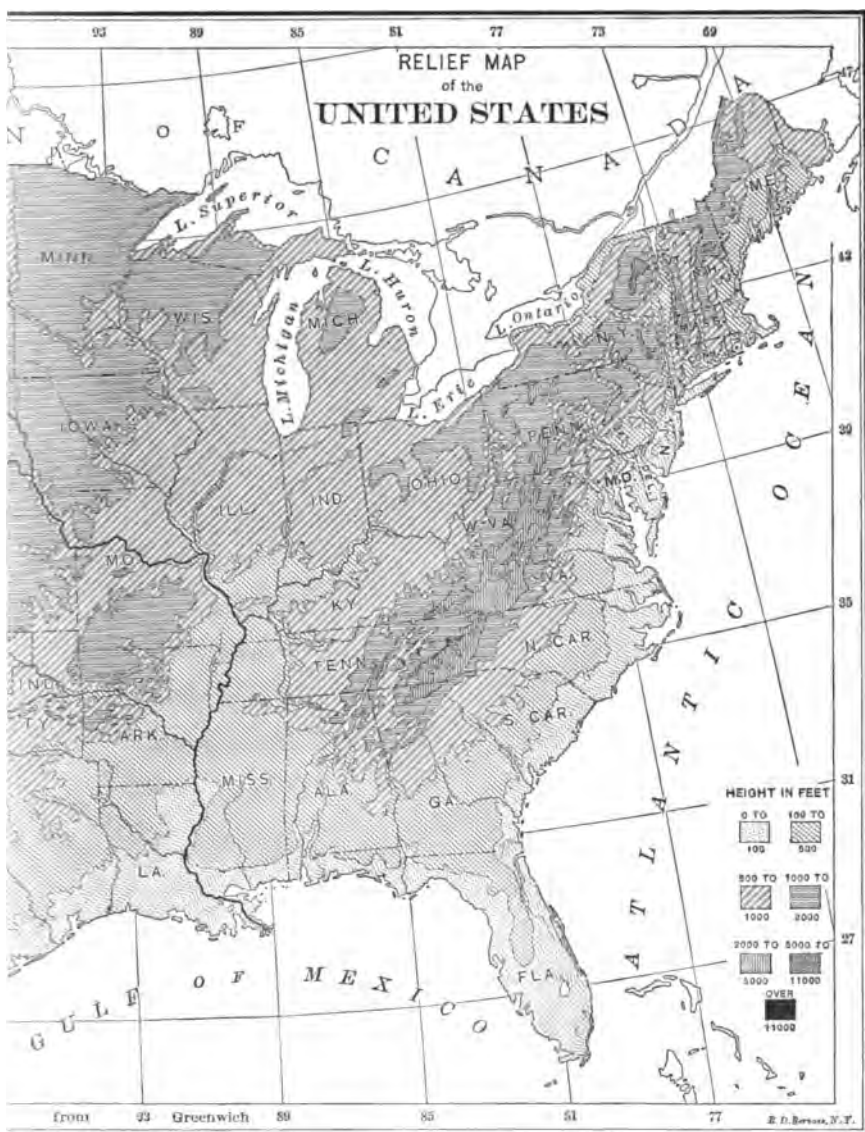
tinents are subject to changes, and that the present form is merely the result of an evolution which has long been in progress. Even at present, in some cases, there are changes of considerable moment still in progress. The mountains which form the border of the continents have been elevated

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by successive foldings of the rocks; the plateaus have been produced by great elevations of the land; and many of the plains have been caused by the filling of seas from the waste of the mountains. Many forces have coöperated to build the continents, but this subject is properly one of pure geology. From the present standpoint, it is enough to know that these changes are going on, and to recognize the fact that the continents are not of the same form at all times. Indeed, there seems good reason for believing that the true American continent does not end at the present shore line, but that its proper boundary is along the margin of the continental shelf, which on the northeastern side, extends to a distance of from 50 to 100 miles from the present shore. At this point the great ocean abysses commence, and from the land to this point there is very little depth to the ocean. (See Fig. 128.)

Physical Geography of the United States. — The best way to illustrate the typical features of the earth's surface, is not to make a hasty survey of the entire surface, but rather to consider a single area in some detail. Thus we may select the United States (Plate 22) as a typical part of the continent, and by examining the physical geography of this area, form an idea concerning the main features of the earth's surface; for we have very nearly every important topographic form represented within the boundaries of this country. For the sake of completeness, it will be well to extend the boundaries of the area described, for a short distance beyond the Canadian boundary, in order to include a portion of the continent which is essential to its proper consideration. This area, including the United States and southern Canada, forms a true section of a typical continent. We may divide this area into five great divisions, each having characteristic geographic features. These are the Atlantic Coast Province,

the Eastern Mountain Ranges, the Canadian Highlands, the Mississippi Valley Plains, and the Cordilleras of the West.

Atlantic Coast Area. — This properly includes the continental shelf, which is now submerged beneath the sea, but which is a submarine plain bordering the continent and appearing to form a true part of it. Above the sea level, the continuation of this area is represented by a narrow strip of level country with an elevation of but a few feet above sea level, and extending from New Jersey to the Rio Grande. It forms a low plain which is nearly featureless, and which in some parts is in the condition of a swamp. It is but a few miles in width in the northern portion, and varies in width as we proceed southward, but gradually increases until the Gulf States are reached. A large part of Florida is included within the area, and along the Mississippi valley the coastal plains expand and extend inland to a considerable distance. The present delta and floodplains of Mississippi, Louisiana, and a part of Arkansas, belong to this coastal area; and in Texas there is a strip whose width is often as great as 50 miles.

On the landward side of this low-lying plain, is a more elevated area of level country, which is also a true plain, but which is more ancient in origin. The low swampy plains are scarcely drained; but these higher, inland plains, are cut by river valleys, and in some cases carved into a series of rounded hills. For the most part, the low swampy plains near the coast-line are of little use to man, their swampiness prohibiting their occupation, though this does not apply to some parts of the plains, such as the delta and floodplain region of the Mississippi. The higher plains on the landward side of these, are much better adapted to occupation, and it is upon these that the greater part of the agriculture of the Southern and Gulf States is carried on.

The Eastern Mountains. — In nearly all cases mountain

chains are found rising above basal plateaus. This is true for the great system of eastern mountains, the Appalachians. Both on the eastern and western sides of these chains, there is a highland country which is a true plateau, though in most cases deeply carved by stream valleys. There are two parts to this system of eastern mountains, one much older than the other, and both considerably destroyed by the sculpturing action of the agents of denudation. The oldest series of mountains date back to the first beginning of the known history of the North American continent, when they were formed as very high mountain chains. A considerable part of New England is included within this area of ancient mountains, and the chains extend southward through the hills of New Jersey, and thence along the eastern base of the modern Appalachians into the Carolinas. In many places these would not be recognized as mountains, but are now in the form of low hills. They have been worn down to their very roots, and nothing but hills are left where once existed very lofty chains. The highest remnants of these mountains are found in New England and North Carolina.

The true Appalachians were much more recently formed; but yet they are among the ancient mountains of the continent. For a long period of time they also have been exposed to the destructive action of denudation, so that their original form is very much altered. They are no longer high chains, and in point of size and grandeur bear no comparison with such recent mountains as the Rockies, the Andes, or the Alps. Formerly they were much higher than now, and probably their features were much more like those of the grander mountains of the globe. At present they consist of a series of ridges and ranges, extending in a northeasterly direction, usually with nearly level tops, and in no case rising to great heights.

The highest part of the eastern mountains is Mitchell's Peak in North Carolina, whose elevation is 6688 feet. In these mountains there are vast stores of coal, building stone, iron, and other products which are of use to man.

The Canadian Highlands. — These are another ancient series of mountains, once much more extensive than now, and they enter this country in only one or two places. The Adirondacks may be considered a part of this highland area, and the same holds true for the hilly region near Lake Superior. At present this region is occupied by a series of low, rather rounded hills, never rising to great mountain heights, and rarely being over a mile above the level of the sea. Among the Adirondacks the highest point is Mt. Marcy, which is 5379 feet above sea level. For the most part this hilly region is of little value, partly because it is situated far in the north, and partly because it is composed of rocks that do not favor the formation of even slopes and deep soil. There are considerable areas of valuable mineral materials, mainly iron and copper. The St. Lawrence valley forms quite another province.

The Central Plains. — Extending from the western base of the Appalachians to the Mississippi, there is a great area of plains, which gradually decrease in elevation toward this river. From the Mississippi westward, the plains continue until the base of the Rocky Mountains is reached; and here also, as the mountains are neared, the elevation gradually becomes higher. At the base of each of these mountain systems, the plains have become transformed to true plateaus, in the case of the Appalachian plateau with an elevation of 1000 or 2000 feet, and of the Rocky Mountains with an elevation of over 5000 feet.

This great area of plains is not everywhere level or rolling, but in some of its parts is broken by truly moun-

tainous irregularities. This is true, for instance, in Indian Territory, in Arkansas, in part of Missouri, and elsewhere. Aside from these limited areas of mountainous character, there are other regions which have been very much cut and dissected by stream action. However, the general condition of these plains is that of gently undulating country. They form the great farming belt of the continent, and also contain deposits of valuable minerals, such as coal, iron, petroleum, building stones, etc. This area of plains is equal to fully one-fourth of the total area of the country, and the elevation is generally less than 2000 feet, while nearly one-half of the area has an elevation of less than 1000 feet.

Since occupied by man, the greater part of this area has been free from timber. In the plains of the far west this is due to the fact that the climate is dry; but among the prairies of the east the cause is less easily ascertained. Some think that, because of its compactness, the soil was unfavorable, others that the timber has been burned off by fires; but neither theory can be considered proven.

The Cordilleran Area.—This is the most complex of our geographical areas, and perhaps should be subdivided, though for our general purpose it may be considered as one great area. In the main it consists of a great plateau, with an average elevation of over a mile above the sea level, above which rise several mountain chains. Commencing on the eastern base of this Cordilleran region, we will examine it in cross-section until the Pacific is reached.

A high plateau reaches to the very base of the Rocky Mountains, which then rise to great elevations, not only above the sea level, but also above the plateau itself. The highest part of the Rockies is in Colorado, in which state there is a total area of nearly 13,000 square miles with an

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elevation greater than 10,000 feet, while several peaks rise above 14,000 feet. The chains, which extend northward and southward, are of varying heights and differ also in extension. There is not one mountain chain, but a series which together make the Rocky Mountains. They pass entirely across the United States, entering Canada on the north and Mexico on the south.

West of these mountains is a region of interior drainage, known as the Great Basin. In reality there are numerous interior basins, some of which combine to form a Great Basin (Plate 23 and Fig. 151), while others exist as separate smaller basins of interior drainage. The basin region is a great plateau area, generally above sea level, and usually more than a mile above the level of the sea. It is commonly surrounded by high mountains, and the interior plateau itself is broken by ridges, known as the Basin Ranges, which extend in a north and south direction.

Bordering the Great Basin on the west, is the Sierra Nevada range, which passes in a nearly north and south direction, from the northern part of California to the southern border of the country.¹ It is a high mountain region, but its average elevation is less than that of the Rockies.

West of the Sierras is a great valley, which, with minor interruptions, extends from Canada to Southern California, where it is interrupted by a mountain mass, to the southeast of which the broad valley continues into the Great Basin, to the Gulf of California, which is really a part of this valley. Death Valley of Southern California, which is a part of the Great Basin, is an illustration of the rather rare feature of an interior basin below sea level. It is 175 miles long, and in one place is at least 225 feet below the level of the sea.

¹ There is no uniformity in the usage of the term *Sierra Nevada*, and the boundaries of the range are vaguely and variously drawn.

West of this valley, and rising almost out of the Pacific, is a fourth series of mountains, the Coast Ranges, which extend from Lower California to the northern boundary of the United States, and apparently as far as Alaska. They are rugged mountains, and among them are found some of the highest peaks on the continent.

These mountains of the Cordilleras are much more recent than those of the eastern part of the continent. Many of them were formed in the Tertiary period, and there is evidence that some of them are still growing. It is as a result of this that they are so rugged and so high; for they have not been long enough exposed to the action of denudation to be reduced to low, rounded forms.

No mention has been made of volcanoes, for the reason that within the borders of the United States, outside of Alaska, there are none known to be active. That this has not always been the case, is shown by the vast number of volcanic cones, in all stages of destruction, which dot the Cordilleran region. There are thousands of these (see Chapter XX.); and on every hand, the evidence is conclusive that in very recent times large areas have been deluged in lava and ash deposits. Along the eastern margin of the country there is no sign of recent volcanic activity, although during the time of formation of the higher mountains, volcanoes did exist.

Aside from being the largest geographic zone of the country, the Cordilleran region contains minerals in extraordinary variety and abundance. It is the great precious metal zone of the earth, and from it is produced more gold and more silver than is supplied by any other region.

The Drainage of the Country. — Three oceans receive the waters that fall in the United States. The accompanying map (Plate 23) shows this so graphically that description may be omitted.

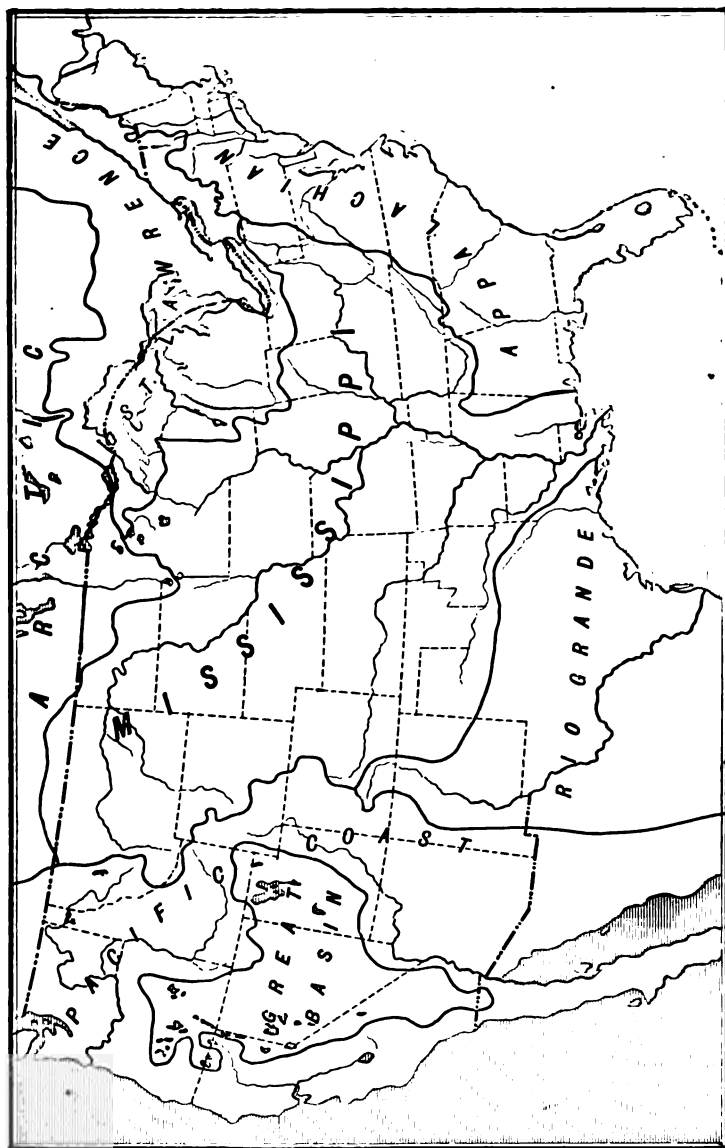


PLATE 23.
Drainage areas of the United States.

The Shore Line. — The coast of North America, like that of several other continents, encloses a land area which is triangular in form, the apex of the triangle being toward the south (Fig. 129). There is much variety in the form of the coast; but the coast line is by no means so broken as that of Europe (Fig. 127). There are several great promontories, notably on the east coast, and many minor irregularities along this coast line; and these are much more prominent in the northern than in the southern part (Plate 22). In the east, islands abound along the coast of Maine, and near Florida. On the Pacific coast there are very few islands, excepting those which begin to be numerous at the northern boundary of the United States, and increase in abundance toward Alaska.



REFERENCE BOOKS.

Whitney. — **THE UNITED STATES.** Little, Brown, & Co., Boston, 1889. 8vo. \$3.00. (In the main reproduced from an article by the author in the *Encyclopedia Britannica*.)

Shaler. — **THE UNITED STATES OF AMERICA.** Appleton & Co., New York, 1894. Two volumes. 8vo. \$10.00. (Particularly Vol. I, in which the relation between man and nature is pointed out.)

Shaler. — **THE STORY OF OUR CONTINENT.** Ginn & Co., Boston, 1891. 12mo. \$0.75. (Of value to the student for elementary reading.)

As a type of the kind of book needed to adequately describe the features of this country, attention may be called to Geikie, — **SCENERY OF SCOTLAND.** Macmillan & Co., New York, 1887. Second edition. 8vo. \$3.50.

For known elevations of points in the United States, see Gannett. — **DICTIONARY OF ALTITUDES,** etc. Bulletin 5, U. S. Geological Survey, Washington, 1884. 8vo. \$0.20. Second edition of same, revised, Bulletin 76, 1891. 8vo. 393 pages. \$0.25.

For average elevation of the states and country, see Gannett, **Thirteenth Annual Report,** U. S. Geological Survey, Washington, 1893.

CHAPTER XV.

RIVER VALLEYS.

General Description. — A river is a natural drainage line



FIG. 130.

A deep mountain valley.

on the land, and it usually occupies a valley which has certain quite definite characteristics.

On either side of the river are the *valley sides* or walls, sometimes rising gently, sometimes steeply: at times to great heights (Fig. 130), and again with only low elevations. In the lowest part of the valley, and generally near its middle portion, the river flows, usually with a meandering course. In most cases the river is immediately bounded by rather steeply rising *banks*, only a few feet in elevation, beyond which the slope is more gentle, and sometimes even a plain,

which in times of flood is covered with water (Fig. 157).

Here and there, at irregular intervals, *tributaries* enter the main stream, and these themselves branch into other tributaries, until very often there is finally produced a branching network of minor streams, all directly or indirectly contributing to the supply of water in the main stream. This principal supply often comes from springs, and sometimes the source of the river is a spring (Fig. 131). Together these form a *river system*; and such a system may have an area of only a few miles, or it may drain an area of many thousand square miles. The line or plane which separates one stream or system of streams from another, is known as a *divide* or *water parting*.



FIG. 131.

Stream issuing from a limestone cave.

All streams have these general characteristics; but when their valleys are examined in detail, there are found to be many differences, not merely between different rivers, but even in the several parts of the same river. The valley of one stream, or a part of a stream, may be a precipitous gorge (Fig. 142), or it may have very gently sloping sides (Fig. 132). In some rivers there are floodplains and deltas, in others these are absent; and in some cases the rock walls of the valley may rise directly out of the river. In some there is a permanent flow of water, in others the supply is intermittent, and in some extreme cases water flows only once or twice a year. In most river systems the tributaries are numerous, but in some cases they are few; and while some of these join the main streams at a high angle, in many cases they enter it at an acute angle. There are many reasons for

these differences in streams, the two most important being the position and kind of rock in which they occur, and the stage in development which they have reached.

Only a very few years ago, river valleys were believed to have been formed by some earth convulsion, or some unusual force, and it was thought that rivers occupied them



FIG. 132.

Brink of Niagara Falls. A valley having very gently sloping sides above the falls and precipitous sides below.

merely because they were valleys ready made. It was believed that the crust of the earth had been contorted and fissured, that ocean floods had swept over the land, and that the rivers had practically no share in the formation of the valleys which they occupied. We now know that the majority of rivers have formed their own valleys, that they have formed them in a very slow way, and that most of them are

still engaged in the work of valley carving. If this be so, then river valleys have had a development and a history; and in this history we may hope to find an explanation of many of the differences.

Development of River Valleys.—We must bear in mind



FIG. 133. A gorge near Ithaca, N.Y., illustrating the down-cutting of a stream valley and its broadening by weathering.



FIG. 134.

Royal Gorge, Col. A mountain gorge where erosion is in rapid progress.

that the river valley is the result of the combined action of stream erosion, which tends to deepen (Fig. 133), weathering which tends to broaden the valleys (Fig. 123), and the transportation of sediment furnished by these means. Erosion proceeds more rapidly than weathering, but there comes a time when its action is checked. In no part of the valley can the stream cut below the sea level, or below *base level*, as it is called; and since it must carry water

down a slope, in its erosion the river reaches lower levels near its mouth than higher up in its course. Until a line of easy slope is reached, erosion exceeds weathering (Fig. 134) ; but then, since erosion is checked while weathering continues, the latter produces its most marked effect, and the valley gradually broadens, while the hills slowly melt



FIG. 135.

Oxbow cut-off in Connecticut Valley, Northampton, Mass. A broad mature river valley with rounded valley walls.

down. Unless interfered with, this would continue until the surface was *base-leveled*, or reduced to a nearly level condition.

Different parts of the river will work at different rates ; and under variable conditions, this development from the cañon or gorge-like valley of *youth*, to the broad valley with rounded sides (Fig. 135), which characterizes the more

mature stages, may proceed at different rates and with different results. Naturally the part of the river which is nearest the mouth is first and most easily developed, for it is nearest the sea level. Therefore a stream valley may have the narrow gorge-like condition among its head waters, while the lower portion is broadened into mature form.

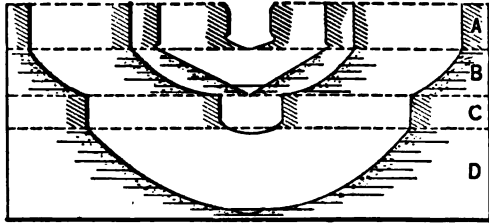


FIG. 136.

Development of the cañon. A and C, layers of hard rock, B and D soft.

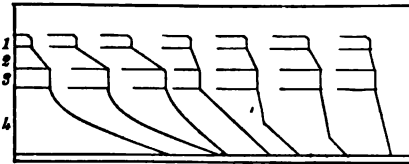


FIG. 137.

Development of the cañon profile in an arid region. 1 and 3 hard, 2 and 4 soft strata.

of broadening by weathering is much more rapid in the soft than in the hard strata.

A stream may be able to cut in one part of its course, and be obliged to deposit sediment in another portion; and in the latter case, erosion is checked, while weathering continues to produce a perceptible effect. In an arid climate, where weathering is relatively unimportant, the valleys are almost all in the condition of

A part of the stream may flow through soft rocks, and another portion through hard layers; and then, even in short distances, the form of the valley may change; for the process

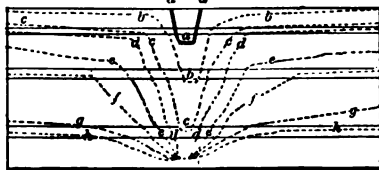


FIG. 138.

Diagrammatic representation of development of a young valley (aa) to old age (hh).

the gorge or cañon (Figs. 136, 137); and among mountains, where the elevation and slope are great, erosion so exceeds weathering that the gorge is the characteristic valley (Fig. 134).

During the time when erosion exceeds weathering,—that is during youth,—the resulting valley is deep and relatively narrow; and wherever we see this kind of valley, we may



FIG. 139.

The Yellowstone, a young valley broadening by weathering and being deepened along a narrow line by the river erosion.

be certain that, for one reason or another, erosion is now, or has recently been in progress. That weathering is also producing an effect, is evident from the fact that the valley is wider at the top than at the bottom, because the former has for a longer time been exposed to its action (Fig. 139). In such cases the river is often a series of cascades or falls, because (see Chapter XVI.) in its rapid down-cutting, the

stream finds rocks of different powers of resistance, and therefore cuts its bed irregularly. Therefore, in addition to gorges, waterfalls characterize youthfulness in river valleys. In many cases lakes are also present; and since the process of lake destruction or removal is a simple and brief task, they do not long remain in the river valley.

The development of the stream proceeds most rapidly near its mouth, and later in the headwaters; and consequently, tributaries are not numerous

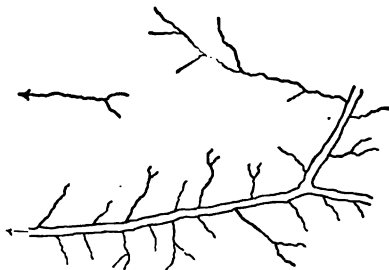


FIG. 140.

A bit of drainage in Illinois, showing slight development of tributaries.

at first (Fig. 140); but one by one they begin to develop, until all of the area is brought under the influence of some stream or rill (Fig. 141). At first the divides are

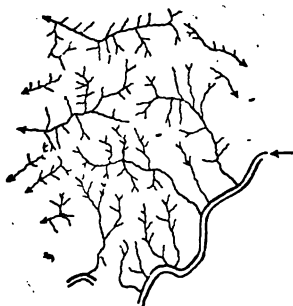


FIG. 141.

A bit of West Virginia drainage, illustrating well-developed tributaries of maturity.

not very definite, and they may be flat-topped and swampy; but in maturity these become quite sharply defined, and usually every part of the area is drained.

When vertical erosion has ceased, the work of the river becomes merely that of a transporter of sediment, except that in swinging about, the river does some lateral erosion on its banks. The characteristics of youth disappear, waterfalls are worn down, lakes are filled and destroyed, the gorge is broadened to the gently sloping valley side (Fig. 138), and the number of tributaries

development. When the river is in the early stage, the development is in the form of a narrow gorge, and the river is in the early stage of its development. In the later part of the river, at the stage the river may consist of three parts — a lower flood-plain, a middle part, and an upper part with gorges and waterfalls. The majority of streams have reached this stage, and this is why, in describing a river, it is commonly said that it consists of these three parts; but really this is to be considered as merely a stage in development, to reach which other stages are passed through, and which is normally succeeded by others. Since all rivers are not in the same stage of development, a careful examination of the valleys of a country shows many exceptions to this condition of early maturity.



FIG. 142.
Canyon of the Colorado.

Naturally there is much difference in the rate of development, and in the result produced under different circumstances. Whether the river develops in a mountain or on a plain, or in an arid or humid climate, the main fact is the same, — that there is this development from immature gorge to broad valley. On a low plain near the sea level, the rate of development in the soft clay is much more rapid than in

a high plateau ; but while in the former there are produced only shallow trenches a few feet in depth, in the latter a cañon may be cut with a depth of thousands of feet. The former we see in the plains bordering the coast of Texas, the latter in the Colorado cañon (Fig. 142). In the hard rocks of the Colorado the form of the cañon is preserved, and this is also favored by the dry climate ; but the soft, clay banks of the Texas streams readily crumble under the action of weathering in a moist climate. The development of the latter to the state of maturity, will therefore be much more rapid than that of the former, — just as some animals or plants pass through life in a few weeks, while others live for a century.



FIG. 143.

A broad Alpine valley.

In a mountainous country the elevation is so great, and the rock structure so complex, that gorges will remain for long periods of time ; and ages must elapse before the erosive action of the river becomes less rapid than weathering. Now and then a deep mountain lake may check the work of the river, and serve as a temporary base level, below which, for the time being, the stream cannot cut ; and so here, for a short distance, the valley may become broadened.

When a river is first formed, it is a small stream that is only a few feet deep and a few feet wide. It is formed by the melting of snow or the rain falling on the ground. The water flows down the slope of the land, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces. The water flows down the stream, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces. The water flows down the stream, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces.



Fig. 16

Flowing gorge in the Alps.

As the river flows down the stream, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces. The water flows down the stream, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces. The water flows down the stream, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces.

Adjustment of Streams. — When a river begins to flow, it is only a small stream. As it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces. The water flows down the stream, and as it flows, it carries with it small stones and pebbles. These stones and pebbles are carried down the stream, and as they are carried, they are broken into smaller and smaller pieces.

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structure, soft layers being the site of valleys, while the hard strata stand out as ridges. This is characteristic of mature streams which have had a long period of development and change.

At first the topography *guides* the stream course, but finally the river course *determines* the topography. In such regions as New England, we find the large river valleys cut in the softer beds of rock, while the harder strata stand up as ridges. Still, here and elsewhere, there are numerous exceptions to this statement, which is only generally true. This *mature adjustment* is well shown in many of the New England and Appalachian streams. Some of the ways in which these changes take place are described in the next section.

The River Divide.—Between any two streams there is a line, or an area, which divides the waters, sending a part one way and the rest in an opposite direction. These divides or water partings are by no means permanent, but are constantly and usually very slowly changing. The stream that has the most power pushes the divide into the territory of the other, and there are various ways in which one stream may have more power than another. One may have a shorter course to the same level, and hence have a greater slope (Fig. 145); or one may be cutting through soft rock, while the opponent is working in hard layers (Fig. 146); or (as in many islands in the trade-wind belt) the rainfall on one side of the divide may exceed that on the other. Gradually the divide moves into the area of the stream having the least rainfall, or the least slope, or the hardest rock.

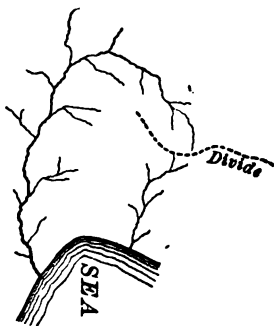


FIG. 145.

A still more important cause for the change of divides is found among tilted rocks. If the layers of a series of strata stand in the monoclinical attitude, and if these alternate in

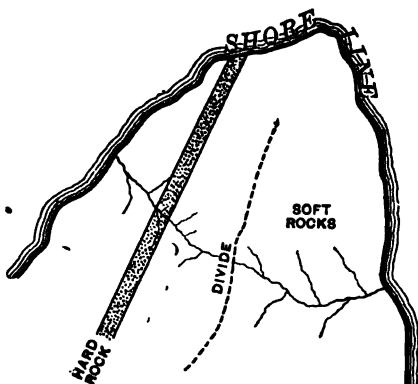


FIG. 146.

hardness, the soft layers weather more rapidly than those which are hard, and which, because of this fact, tend to remain above the general level (Fig. 261). In such a case, the highest points do not sink vertically as the ridges wear down; but they move downward and backward in the direction

of the dip of the strata (Fig. 147). This is so permanent a condition that it may be stated as a law, that in rocks of monoclinical attitude the divide migrates in the direction of the dip. This law of *monoclinical shifting* applies also to changes in river courses. In their down-cutting, the valleys also tend to migrate in that direction, and this is one of the reasons why streams adjust themselves to soft layers; for once finding them, they tend to remain in them.

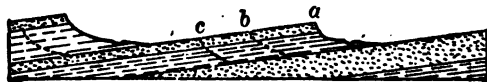


FIG. 147.

Illustrating monoclinical shifting of divides.

Usually the migration of a divide is an extremely slow process, and in the course of a lifetime one would not notice any change; but under exceptional circumstances it may become rapid, and in a brief time the divide may change for many miles.

This will happen when a river with a more favorable situation, for some reason gradually pushes its divide back until it taps its opponent. Then the stream receives a large accession of drainage area and carries a part of another system across the old divide (Fig. 148). Before the diversion, the divide was low and nearly on the same level as the stream about to have its course changed; and then, perhaps during some time of flood, the new course was chosen and afterwards maintained.

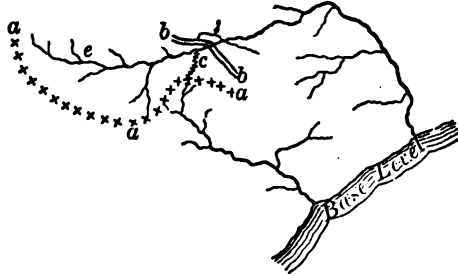


FIG. 148.

Illustrating sudden shifting of a divide (*aa*) to (*bb*) by carrying the headwater (*e*) across the old divide at (*c*).

While these cases undoubtedly occur, it is doubtful if they

are at all common; and the ordinary change in the divide is a very slow one. By these changes in divides, the adjustment of streams is also favored.

Accidents to Streams.—River valleys tend to pass through a regular cycle of development, from the young to the old stages; and if nothing intervened to prevent, we should find them all in some stage in this regular cycle. Some would be young, others mature, and others old; some would be upon plains, others on plateaus, or among mountains. There would be great variety in river valleys, but it would be of a regular kind. In reality, the development of rivers is subject to many interruptions of various kinds, and the cycle is never entirely passed through by any single river. The accidents to which rivers are subjected, sometimes increase, sometimes decrease, the power of the stream. In the course

of its development, the different parts of a river may experience entirely different accidents, and the resulting valley will be *complex* or *composite*. Any single part of a stream may also suffer a variety of accidents.

Land Movements. — Land movements are among the most common accidents which interfere with normal development ; and these are of three kinds : (1) broad uplifts, (2) downward movements, (3) folding which accompanies mountain formation. With the general uplift of a country, streams are given new life, or *rejuvenated*, and we may then have a narrow gorge cut in the center of a broad valley. After a long period of denudation the uplift gives new powers to

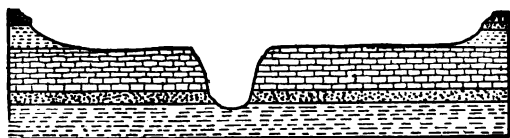


FIG. 149.

Diagram showing the result of an elevation, which caused the inner cañon of the Colorado to be cut between the older walls of the outer and broader valley.

the stream, and it then cuts a narrow valley (Fig. 149). Such an uplift may affect great areas ; and in the rivers thus *revived*, waterfalls

again begin to develop, and nearly all of the appearances of youth may return. Nearly every stream system shows some sign of this kind of rejuvenation, which has affected its recent development. If this elevation happens near the sea-coast, a part of the ocean bottom is raised to the condition of dry land, and the streams of the old mainland extend across it ; and perhaps by this means separate streams may be united to form one system.

Depression of the land would rob streams of some of their force by decreasing their elevation, and hence their slope. Along the coast, the lowering of the land causes the ocean to extend up the valleys, *drowning* parts of the streams, and transforming their mouths to estuaries or straits, while



PLATE 24.

River valleys drowned by submergence beneath the sea.

numerous islands are formed where the hilltops rise above the sea (Figs. 193, 211 and Plate 24). This entrance of the sea produces a reverse effect from that of elevation; for the lower parts of streams may be *dissected*, and parts of one system may enter the ocean through separate mouths. This is very well illustrated in many cases on the coast of Maine, and particularly well in the Chesapeake (Plate 24), which, with its tributary streams, represents a part of a river system drowned by the sea.

When the strata are folded in the form of mountains, stream erosion is interfered with and often entirely checked. As the mountains rise, a dam is built in the path of the rivers; and unless their rate of down-cutting is as rapid as the rate of elevation, which in most cases would not be true, the streams will suffer interruptions. If they persist in their course, and cut their channels as rapidly as the mountains rise, they are known as *antecedent* streams. It is doubtful if there are many cases of rivers now crossing a large mountain in exactly the same course which they occupied at a time antecedent to the mountain formation; but many geologists believe that the Green River, where it crosses the Uinta Mountains of Utah, is an illustration of this type of stream.

Ordinarily the folding would locally transform the river to a lake, and as the dam continued to grow, the lake would gradually become deeper and more extensive. With the formation of the lake the erosive power of the stream decreases; for when it flows from the body of quiet water, it has been robbed of its sediment supply, and is therefore unable to do much erosive work. If the mountain growth is rapid, it may even cause a stream to flow in a direction opposite to the course which it originally had—it may be *diverted* or even *inverted*. Where the rocks in the middle

course of a river are rapidly folded during mountain growth, a stream may even be separated into two parts.

With the growth of the mountain, since the river slope is increased, new tasks are set before the streams. Gorges and waterfalls are caused, and because of the great elevation of the mountains, these continue for a long time; and thus long-continued youth is impressed upon the mountain valleys. Every mountain furnishes illustrations of these latter features; and in many, such as the Alps, there are also lakes, which are the result of mountain folding, and which represent the interference with stream erosion which is brought about by the growth of mountain dams.

Climatic Accidents.—A change of climate to a condition of dryness, robs streams of their erosive power; but even more markedly does it decrease the power of weathering. Hence such a change favors the angular type of valley. It reduces the number of streams (Fig 150), and causes those which remain, to be dry for a large part of the time; and hence in a dry country, there are large areas unoccupied by drainage lines. A rare, heavy rain, falling upon such an undrained surface, carves a temporary valley, or *arroya*, which may never again be occupied by water. Stream valleys may be permanently abandoned, while others may be only *withered* or *shrunk*. By the increasing dryness of the climate, lakes may be evaporated and great basins of interior drainage be formed. Therefore, stream systems may be dissected by this cause also, and channels of outflow of lakes may be abandoned (Fig. 151), while the direction of the drainage changes from the sea to the lowest point of the old lake bottom; and this causes many other peculiar changes of a minor nature. By this action, a part of the Great Basin which was once tributary to the Pacific, through the Columbia, is now transformed to the Great Salt Lake interior drainage area.

The change in climate which produces glaciation, first covers all the country with ice and buries the valleys. Near the margin of the snow-covered area, streams may be separated, and an entire change in the drainage be caused.



FIG. 150.

The drainage of an arid region

Among the effects of the ice front, is the interference with streams that flow toward the ice, which acts as a dam, transforming them to lakes, and causing them to overflow across some divide. When the ice of the North American conti-

mental glacier (see Chapter XVII.) was melting from the surface of the country, many such lakes were produced, and some of them were of great size. The St. Lawrence system was dammed, and lakes were produced in different positions from those occupied by the present Great Lakes. During the same period, the valley of the Red River of the North was transformed to a great lake which overflowed to the Gulf of Mexico, instead of to the Arctic, as the present drainage directs.

Some streams had their courses permanently changed and even reversed. When the ice melted, it left much drift material upon the surface; and this soil sometimes completely buried the old valleys, so that entirely new channels had to be cut. More often this filling was only partial, and streams were turned from their course for short distances, and often dammed into lakes, which in many cases are now represented by swamps (Plate 25). Hence in a glaciated region we may have very complex streams; for in broad, mature valleys, local post-glacial gorges may be cut, while here and there falls and lakes exist. The streams are often given new life, or rejuvenated, either through their entire course, or for a short distance. Often the course forced upon them is very much more roundabout than that pursued before the



FIG. 151.

The Great Basin. The lighter shading shows the former extension of lakes when the Great Salt Lake overflowed into the Columbia.

glacial period (Fig. 152). Illustrations of the various effects of glaciation abound by the thousand in the glacier belt

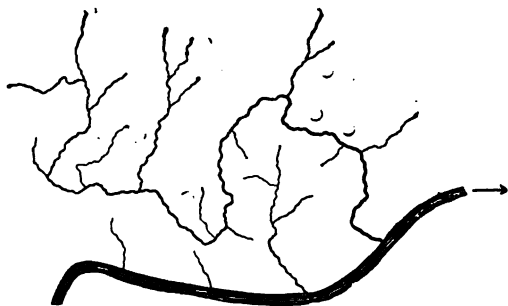


FIG. 152.

Diagram of a river caused to flow irregularly because of glacial deposits in its course, which prevented it from entering the main stream by its preglacial course, now partly occupied by a tiny stream.

of New England, New York, and other of the Northern States. Nearly all of the gorges and lakes in this belt are the result of the condition of glaciation. While the most notable instances are those of the Great Lakes and Ni-

agara, these are merely large examples of a great group.

Other Accidents. — Interference with river valley development is commonly noticed in regions of volcanic eruptions. Sometimes the valleys are filled with lava ; at times the streams are forced to cut new valleys in a part of their course ; again they are transformed to lakes ; and they may even be forced to flow in a reversed direction. Here again, the valleys are rejuvenated, and gorges and falls are produced. Illustrations of these features may be seen on almost any map of a region of volcanic activity.

An avalanche in a mountain may produce one or all of these effects, and there are other minor accidents to which streams are subjected. Sometimes river valleys are again and again subjected to one or several of these accidents, and their cycle of development much interfered with. This is why youth and early maturity are the characteristic features of most valleys ; for the stage of old age cannot be reached,



PLATE 25.

Drainage in the glaciated region of Wisconsin, showing the abundant swamps (indicated by dashes) between the drift hills, and the interference of these hills with the stream course.

because in the conflict between denudation and the internal forces of elevation, the latter are more powerful and keep the streams either constantly or intermittently at work in valley formation.



REFERENCE BOOKS.

From the text books of geology, previously referred to, one may obtain additional information upon some parts of the subject treated in this chapter.

Important articles on the DEVELOPMENT OF RIVERS will be found in the National Geographic Magazine, Washington, D.C., Volumes I. and II. These are from the pen of Professor W. M. Davis. This magazine is a very valuable one for teachers of geography. Six volumes have been published, the price to the public being \$2.00 each for the first two, and \$3.00 for the others. To members, they are sold at a lower rate; and each member receives the Magazine. The cost of membership is \$2.00 a year, and any one interested in geography is eligible.

The remarkable COLORADO CAÑON is fully described by Dutton in *Monograph II* (with Atlas), U. S. Geological Survey, Washington, 1885. \$10.00. The Atlas is splendidly illustrated. For a shorter account, see *Second Annual Report U. S. Geological Survey*,¹ Washington, 1882. Powell's "Exploration of the Colorado River of the West," Washington, 1872, now unfortunately out of print, but still on sale at the second-hand stores, is a most fascinating description of travel, as well as a scientific description of this wonderful region. The same author has published upon the same subject "Canyons of the Colorado." Flood & Vincent, Meadville, Penn., 1895. 4to. \$10.00.

Huxley. — *PHYSIOGRAPHY.* Macmillan & Co., New York, 1891. 12mo. \$1.80.

(A study in physical geography, in which the Thames Basin is taken as the central topic.)

¹ Many of the annual reports of this survey may be obtained by the aid of congressmen, though the earlier ones are now exhausted. They contain much valuable material, written in a sufficiently popular manner for the non-geological reader. Reference is made to many of these articles in the later chapters.

CHAPTER XVI.

DELTA, FLOODPLAINS, WATERFALLS, AND LAKES.

Deltas. — Nearly all streams carry sediment; and if for any reason the velocity is suddenly checked, some of this material must be deposited. The most favorable situation for the deposit of river sediment, is where the stream enters another body of water. In such places the material is deposited near the stream mouth, and a delta often results.

Where streams come from steep mountain valleys upon relatively level plateaus, the sudden change in slope causes the deposit of some of the sediment at the mountain base. This material is dropped most abundantly near the mountain, and the rapidity of deposit decreases away from it. As a result of this, a fan-shaped deposit is produced, to which the names *alluvial fan*, *fan delta*, or *cone delta* are commonly given (Fig. 155). These deposits are very common in arid regions; and although relatively rare elsewhere, when they occur in moist countries, they are usually flatter and less distinct. The apex of the fan extends up the stream toward the mountain base.

The formation of true lake or ocean deltas, depends upon a variety of circumstances. There are many large streams which are not forming deltas in the sea. In some cases this is due to the fact that the streams carry very little sediment; in other cases, the sediment brought to the sea is mostly carried away by currents. In general, delta formation is not favored in open seas, where tidal currents and waves are

delta formation is absent, and this is the reason why deltas in the sea are so uncommon. In many cases the submergence of the coast has transformed the river mouths to estuaries, instead of admitting of the formation of deltas.

By far the most favorable conditions for the formation of deltas are found in lakes. Here there are no tides, waves are only moderate in effectiveness, and the depth is comparatively shallow, and usually not increased by subsidence of the bottom. The lake water acts as a filter, removing all the sediment which streams bring, and the greater part of this is deposited, almost immediately opposite the mouth of the tributary. With these very favorable conditions, in nearly every lake deltas occur opposite the mouths of most of the streams; and in some cases, by the growth of two deltas from opposite sides, lakes are divided into two parts, as at Interlaken in Switzerland.

Over large deltas, the streams flow in uncertain course, sometimes changing their channel from one side of the delta to the other, as is so frequently done on the delta of the Yellow River of China. In this way much destruction of life is accomplished. Over the nearly level delta, the main stream divides and often subdivides, entering the sea through a number of branches, which may be called *distributaries*, in distinction from the tributaries, which *bring* water to the stream, while these *distribute* the river water to the sea (Fig. 153). As a result of this branching of the streams, and the changes in river channel, in course of time all parts of the delta are traversed by sediment-bringing water; and in this way the delta front is made to advance into the sea, while the delta itself is built up above the sea level (Fig. 154). In the course of the growth of the delta, the advance is often irregular, and arms of the sea may be enclosed in the form of lakes (Fig. 153). The form of the delta is

roughly triangular, or like the Greek letter Delta (Δ), whence its name. This is really a partial though somewhat distorted cone, not unlike the fan delta itself (Fig. 155).

Floodplains. — Rivers are very often given more load than

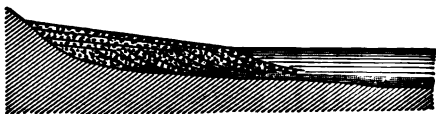


FIG. 154.

Diagram to show the mode of formation of a delta.

they are able to carry, and of necessity they are obliged to deposit some. The material is sometimes deposited in the form of *bars* in the stream channel, or at

other times it is spread over the valley at one side of the channel, particularly when the stream has quantities of sediment during flood times. In this way, by laying aside parts of the sediment load, the stream is forming floodplains.



FIG. 155.

An alluvial fan.

There are numerous ways in which these may be caused. They are sometimes merely temporary deposits, being formed at the same time that the stream is cutting its channel deeper. At certain seasons of the year, the river is obliged for a while,

and locally, to put aside some of its load, and this it does, forming narrow floodplains which are often composed of very coarse materials (Fig. 156). We find such floodplains very commonly among the mountain streams.

Usually floodplains are due to a decrease in the river slope, a decrease which normally occurs between the headwaters and the mouth. Supplied with much material from the



FIG. 156.

River bed and floodplain among the mountains.

upper parts of the valley, the stream reaches these regions of less slope with decreased ability to transport the sediment ; and some of it must be deposited. This is due to the fact that streams are able to transport sediment in proportion to their velocity, which itself depends partly upon slope and partly upon volume. By far the greater number of the large floodplains of the world are due to this decrease in river slope, from upper to lower portions.

Sometimes the broad floodplain is in part a delta, which has been left inland by the encroachment of the delta upon the sea. In the Mississippi valley, the delta began to form above the northern limits of the state of Mississippi, and has grown outward into the Gulf, filling the estuary which existed there, and transforming it to a broad floodplain, as we now find it. This change is something like that which would happen if the streams now entering Chesapeake Bay



FIG. 157.

Floodplain of a great river.

should fill up the bay, as they are doing, and change it to a level plain composed of fine-grained materials brought down by the rivers.

A change in the level of the land, tilting the seaward portion of a stream so as to decrease the slope, may also bring about conditions favoring the formation of floodplains; and any cause which increases the sediment, also favors this formation. If a stream channel is graded to a given volume of water and sediment load, an increase in the sediment will necessitate the deposit of some, and this will produce a floodplain; or a decrease in the volume, such as would result in

the change of climate from moist to dry, if the sediment load is not also decreased, will bring about floodplain formation. From this it is seen that floodplains are formed by quite different causes.

Their characteristics are rather simple. For the most part they consist of remarkably level plains (Fig. 157), usually partly swampy, and composed of fine soil, which is generally

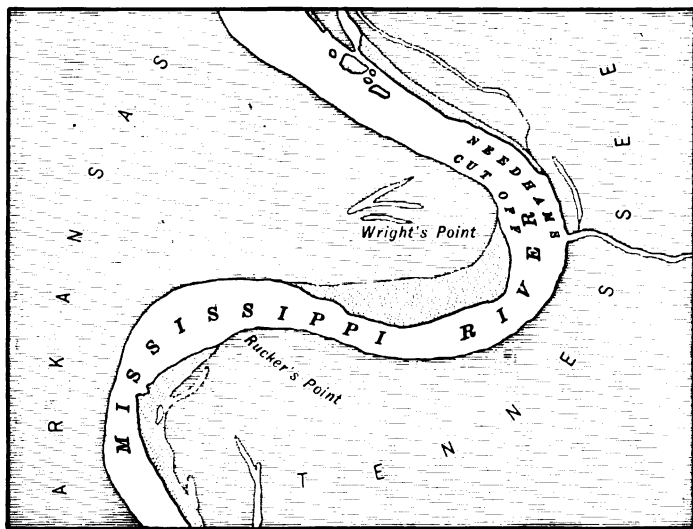


FIG. 158.

so rich that the floodplain regions are important agricultural districts. The main stream meanders through the plain in great swinging curves (Figs. 135, 172, and 157-160); so that its course is sometimes greatly increased in length. On the Mississippi, a steamer is often within a few hundred yards of a portion of the river which can be reached by water only by a sail of several miles. These, which are known as oxbow curves, are constantly changing in form and hence

in position. The river is eating its way into the floodplain on the concave bank, and depositing upon the convex bank

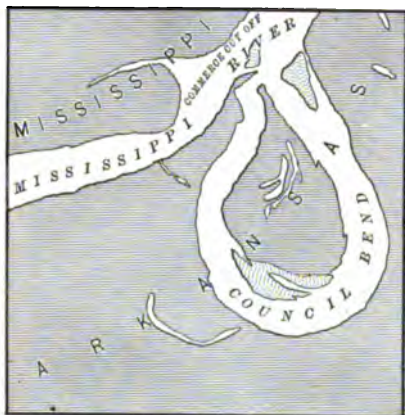


FIG. 159.

(Figs. 158-160, in which the dotted areas represent sand deposits). This process of change often causes the river to cut across the narrow neck of land between two parts of the curve, and thus shorten the course and abandon the old curve. In delta and floodplain regions, these are known as oxbow cut-offs (Fig. 159) ; and after they are

formed, they become crescent-shaped lakes, and sometimes they are almost complete circles. In the course of time these lakes are destroyed by being filled with sediment when the stream is in flood, and when the floodplain is submerged beneath the river water (Fig. 160).

These great floodplains are constantly being raised by the deposit of sediment ; and the time of their formation is that of the flood stage of the stream, when it is no longer confined to its channel, but

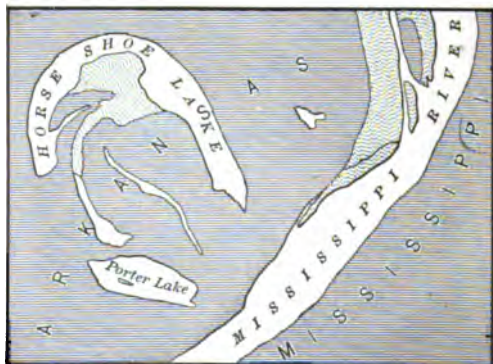


FIG. 160.

overflows and submerges the great level tracts on either side. Sediment is being deposited from this great expanse of water, because the velocity is decreased in these shallow areas. It is to prevent this flooding that the levee banks are built on the margin of the floodplain of the Mississippi. These banks are built to a sufficient height to shut out the high water from the floodplains.

While the stream is constantly at work building up its floodplain during floods, by its meandering it is constantly at work removing portions; and so there is a process of intermittent movement of sediment, from up stream down toward the mouth. It is deposited during flood; later it may

be attacked by the lateral cutting of the stream, and then it is carried a step down stream, perhaps to be deposited again, and then after awhile to again start in movement.

Upon a floodplain the tributaries to a river enter the main stream at very acute angles. The slope is so gentle, that the deposit of sediment near the mouth of the tributary constantly tends to divert the river further and further down stream. On floodplains, the tributaries often flow for many



FIG. 161.
Falls of the Yellowstone.

miles in a course nearly parallel to the stream which they would join; and in some rivers, the tributary streams have been so far deflected that they enter the sea independently.

Waterfalls.—When for any reason a stream has a sudden descent in its channel, waterfalls or rapids are produced (Figs. 161–166); and we cannot separate the two phenomena, because there is every gradation between them. There are many ways in which an unnaturally steep slope may be introduced into the stream channel. One of the most common means is by the accidental diversion of the stream



FIG. 162.

Taughannock Falls, New York. Caused by change in a river course due to glacial obstructions.

from its course. The great majority of waterfalls in the United States have been caused by changes in the stream courses, the result of some interference on the part of glacial deposits. As a result of these glacial drift accumulations in stream valleys, in many cases the rivers have been turned to one side, and caused to flow over steep descents, producing either a series of rapids or of waterfalls (Fig. 162).

The thousands of waterfalls in northern United States are mostly the direct result of this kind of accident; and Niagara (Figs. 132 and 163) may be taken as a typical illustration of this kind of waterfall.

At the close of the glacial epoch, the Niagara River flowed from Lake Erie to Ontario along its present course, and

entered Ontario after a sudden descent over the bluffs at Queenstown (Fig. 169). Glacial deposits left by the ice had so filled the old channel, that this new course was the natural outflow of Lake Erie. The waterfall produced in this way, has been gradually retreating backward toward Lake Erie, and at present is seven miles from its former position. In



FIG. 163.
American Falls, Niagara.

the process of this retreat, the gorge has been cut to a depth of from 200 to 300 feet, with a width of from 200 to 400 yards, while the fall itself is now about 160 feet in height. Careful surveys made many years apart, show that the retreat of the waterfall toward Lake Erie is rather rapid, on the average being not far from five feet a year. If this average has been maintained throughout the entire history of Niag-

ara, the time occupied in cutting the gorge from Queenstown to the base of the falls, is somewhere between 7000 and 10,000 years. The falls of St. Anthony, in the Mississippi valley, are of the same origin, and have had nearly the same history; and the same is true of a vast number of waterfalls in the northern states of the Union.

Any other obstacle in the way of a stream will transform it into a waterfall, such for instance as the folding of moun



FIG. 164. Yosemite Falls.

tains, or the passage of a lava flow across a stream valley, or any one of several similar accidents. When rocks break, and move on one side of the crack, as is done when faults occur, the movement increases the slope of the stream near the fault line. Thus between the plains bordering the eastern coast of the United States, and the hilly region just inland from these, there is a line of movement, on the landward side of which the country has been raised; and this line has determined the existence of a large number of small falls and rapids. Because of this it has been called the *fall*

line; and this small geological accident has been largely responsible for the location of several of the great cities along the Atlantic coast. The falls and rapids mark the approximate limit of navigable waters, for ships cannot pass over them; and since the cities were so placed in order that they might have the advantage of ocean traffic, and still be as far inland as possible, they were usually located at the head of navigation. Thus such cities as Philadelphia, Baltimore, Washington, and others, are situated just on the seaward side of this fall line, and small falls and rapids are found almost within the city limits.

As a stream deepens its channel, it may actually *form* waterfalls as a result of its work. The river is able to remove soft rocks more rapidly than hard ones, and if the stream channel is crossed by layers of different hardness, the difference in rate of cutting in the two kinds of rock will produce a rapid, or even a waterfall (Figs. 162, 163, and 165). The hard layer tends to stand up above the soft one, and thus there is a steep descent in the stream valley. As soon as the stream has cut down to the line where its power of deepening ceases, the waterfalls disap-



FIG. 165.

Small waterfalls in a gorge near Ithaca, N.Y., where the water flows over nearly horizontal rocks of varying hardness.

pear. Falls of this origin are particularly common in regions of horizontal rocks; for here the waterfall tends to retreat upstream (Fig. 166), and hence remains for a long time. Indeed, it remains until the stream has eaten its way far enough back to have escaped these differences in rock structure.

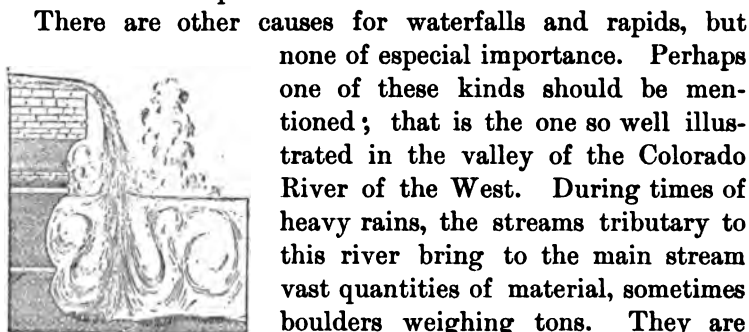


FIG. 166.

To illustrate the probable condition at Niagara, where the water falls over a hard limestone stratum, beneath which are softer layers.

There are other causes for waterfalls and rapids, but none of especial importance. Perhaps one of these kinds should be mentioned; that is the one so well illustrated in the valley of the Colorado River of the West. During times of heavy rains, the streams tributary to this river bring to the main stream vast quantities of material, sometimes boulders weighing tons. They are able to do this because they enter the main stream with very rapid slope,—much more rapid than that of the Colorado itself. Opposite their mouths they build up these coarse fragments, which the river itself is not able to remove; and over these bars the water flows in rapids, which are sometimes so well developed that it is almost impossible to travel down the stream in a boat. Only one or two parties have succeeded in passing through this cañon, and they experienced many dangers which were caused by the rapids of this origin.

Lakes.—A lake is properly a part of a river, and it may have been formed by one of several causes. There are many differences in lakes; some are fresh, others salt; some have tributaries from the surface, others are mainly if not entirely supplied with water from underground; some have outlets, and others are without them. In form and in depth there is

almost infinite variety; but in all cases they will be found to be parts of river systems.

Anything that changes a stream valley so that the bottom becomes a trough or basin, will produce a lake. By far the most common cause for this is the effect of glacial deposits (Chapter XVII.). The stream valleys which were carved before the ice covered the country, were dammed, or in other ways interfered with by glacial deposits, or by glacial action, so that when the ice retreated, the rivers found it impossible to flow over the land without becoming locally transformed to lakes (Fig. 167). The scores of thousands of lakes and ponds that exist in northern United States and Europe, are mostly due to glacial action (Figs. 168 and 190). Other accidents to rivers



FIG. 167.

Avalanche Lake, Adirondacks, N.Y. Part of a river valley transformed to a lake. (Copyrighted, 1889, by S. R. Stoddard, Glens Falls, N.Y.)

may produce lakes in a similar way. Thus a lava flow may dam a stream and form a lake; or an avalanche may do the same; or the growth of a mountain across a stream valley may transform it to a body of quiet water. A large majority of the lakes in the world are a result of accidents, either of these or other kinds. In many cases the origin is complex, several causes uniting to produce the lake basin.

Not a few lakes in the world are the result of other causes. Original depressions on the surface of a land which has

been newly added to the continent, when filled with water are formed into lakes. This is the origin of the large number of lakes in Florida, and of Lake Drummond in the Dismal Swamp. Others may be produced during and as a result of the natural development of streams. Such lakes as the oxbow cut-offs described above (Figs. 135 and 160), or those formed by the irregular growth of deltas (Fig. 153), are dependent upon the development of streams.



FIG. 168.

Glacial lakes in the Adirondacks.

Lakes are merely temporary phenomena, forming but one stage in river development. They are speedily removed, and any lake which exists in the course of a stream, acts as a barrier to river development so long as it remains. The removal of lakes is usually accomplished by the combination of two processes of river work: one, the filling of the lake, the other, the cutting of the barrier. Lake-filling is by far the most important, and nearly every particle of sediment that comes into the lake waters, works towards this end of destruction.

Unless the conditions are exceptional, the process of down-cutting at the outlet of the lake is relatively unimportant. For streams which emerge from these quiet bodies of water have very little working power, because all sediment has been removed by the lake, and the stream has thus been robbed of the tools with which it commonly does its work. It is still able to act chemically; but this is one of the least important means which streams have for cutting

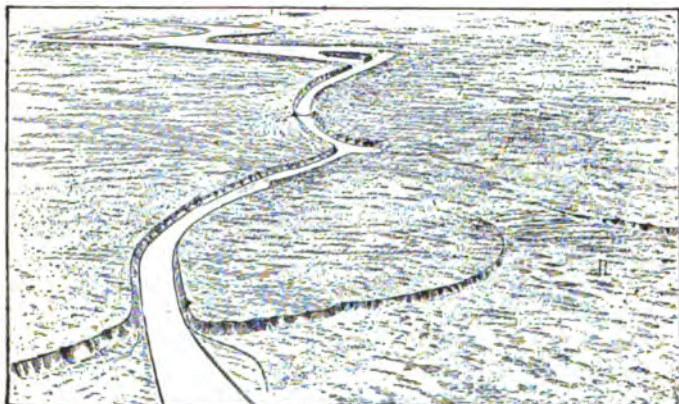


FIG. 169.

Bird's-eye view of Niagara gorge and falls.

their channels. For instance, the Niagara emerges from Lake Erie through a valley which is scarcely perceptible (Figs. 132 and 169), the river flowing almost on the surface of the plain; and in all the time that this stream has drained Lake Erie, it has done almost no work of channel formation between the lake and the falls.

If the rock which forms the barrier to a lake is composed of very soft materials, which the water is easily able to remove, or if it is easily soluble, the barrier may be rapidly

cut down, and thus the lake be speedily drained. Or if, after emerging from the lake, the stream finds itself precipitated over some steep slope, its power of working is so concentrated by this waterfall, that it rapidly wears a channel, as has been done by Niagara between Queenstown and the falls. Niagara is wearing back its falls towards Lake Erie; and given time, as a result of this concentration of work, it will so lower the outlet as to completely drain Lake Erie.

Lakes may be partially or entirely destroyed by evaporation, as has been the case in the great interior basin of the



FIG. 170.

Shore lines of extinct Lake Bonneville.

west. Here there formerly existed numerous large lakes, some of which had outlets to the sea (Fig. 151). By a change in climate, arid conditions replaced those of moistness, and the lakes shrunk, until now there exist in their place, either alkaline desert plains, or shallow salt lakes without outlet. The streams are constantly bringing small quantities of salt, and this is gradually accumulated as the water evaporates; so that in time, the fresh water becomes salt, and this may go on until some of the salt is precipitated in the lake bottom.

A change to a moist climate would again transform these basins to large, fresh-water lakes; and in the complex history of that interior basin region, such an alternation of climate has occurred. The geological history reveals two moist periods, with intervening dryness; and now within sight of Salt Lake City, the beaches (Fig. 170), bars and cliffs, formed by the waters of these ancient lakes, may be readily seen extending along the mountain base. So distinct are they, that even the cowboys have



FIG. 171.

A Florida swamp.

recognized the fact that water formed them. One of these extinct lakes, the ancestor of Great Salt Lake (called Lake Bonneville), had an area of 19,750 square miles, with a depth of 1050 feet. It covered an area now occupied by fully 200,000 people, and its depth near the great Mormon temple was 850 feet.

Swamps. — The usual way in which lakes are removed, is by the combination of the two processes of filling and down-cutting; and generally lake-filling is of more importance

than the down-cutting of the outlet. In the glacial belt of northern United States, where lakes of all sizes were formed when the ice retreated, we find abundant illustration of every stage in the destruction of lakes. The more shallow of these have been transformed to swamps, which are usually a final



FIG. 172.

Ray Brook, Adirondacks.

stage in the process of lake destruction (Fig. 172). After the sediment has elevated the bottom of the lake nearly to the surface of the water, vegetation commences to grow and to increase the rapidity of lake-filling.

At first the plants are sedges and other species characteristic of lakes; then they are replaced by mosses; and finally the swamp becomes transformed to a forested area, which is the last step in the change from lake to dry land.

There are other causes for fresh-water swamps. The interference with drainage on the part of vegetation, may produce swamp conditions. The sphagnum moss, which is the form of vegetation causing the peat bogs of the north, by growing near the outlet of springs may transform these into bog areas, even upon hillsides; and the growth of reeds, and other forms of vegetation, along sluggishly moving bodies of water, may transform them into swamp areas. The Dismal Swamp, with an area of 1500 square miles, appears to be partly due to this cause. The flooding of rivers also produces swamp conditions. But by far the largest number of swamps are the direct result of the destruction of lakes. This is illustrated in the Florida swamps (Fig. 171), as well as in those of the glacial belt.

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See also Russell's *LAKE LAHONTAN*, Monograph XI., U. S. Geological Survey, Washington, 1885. \$1.75. (Short abstract of the same in the Third Annual Report of the Geological Survey, 1883. In later reports there are one or two other articles, by the same author, on the ancient lakes of the Great Basin.)

For *SWAMPS*, see Shaler, U. S. Geological Survey, Tenth Annual Report, Washington, 1890.

For *NIAGARA*, see Gilbert's discussion in the Smithsonian Annual Report for 1890 (pages 231-257), Washington, D.C.

For *SHORE LINES*, see references for Chapter XVIII.

¹ The subjects of this chapter, as of some others, are not yet treated in a complete way in books of popular interest, and the literature is widely scattered, and often in very inaccessible publications. In some of the text books, and general books of reference, these subjects are treated from certain standpoints. Some of the monographs of the National Geographic Society (published for use in the schools, at the price of \$0.20 each) now being issued by the American Book Co., New York, promise to fill these gaps. Exact reference cannot be made to them, since at the time of writing, only one or two of the preliminary numbers have been issued.

CHAPTER XVII.

GLACIERS.

Cause of Glaciers. — A glacier is an accumulation of snow, for the most part solidified into ice, which is engaged in a slow movement from one place to another. When the snowfall is so great that the warmth of summer is unable to entirely remove it, the conditions favoring the formation of a glacier are brought about. Year after year the snow accumulates (Fig. 173), and in the course of time this accumulation makes movement necessary, for it flows according to certain laws. As a result of this



FIG. 173.

An Alpine snow field.

movement, particularly when it occurs among mountains, the ice stream may extend far below the snow line; and in the Alps, the ends of glaciers are sometimes near fields of growing grain. They extend down until they reach a place

where the warmth of the sun is sufficient to melt them, and therefore to stop their further movement. This place is not a fixed line, but may vary from year to year, so that the front of a glacier often retreats and advances.

The conditions at present favoring the formation of glaciers, are found either in high mountains, or else in lati-



FIG. 174.
Whitney glacier, Mt. Shasta.

tudes within the Arctic or Antarctic circles. There was a time when these conditions existed further south, and then general glaciation was brought about in regions now within the temperate zone. There are two quite distinct classes of glaciers: the valley or alpine, and the continental glacier.

Alpine or Valley Glacier.— This form of glacier receives its name from the fact that it is generally developed in

mountain valleys, and is particularly well developed among the Alps (Fig. 175). We also find valley glaciers among most of the mountains of Alaska (Plate 26), in British Columbia, in some of the high mountains of Washington, such as Mt. Shasta (Fig. 174), and in several places in the Sierra Nevadas (Fig. 177). The glaciers of the west are small and insignificant, but those of Alaska are among



FIG. 175.

The Rhone glacier, showing the ice stream from snow field to terminus.

the best developed in the world. Valley glaciers are by no means uncommon in other parts of the earth; and, among other places, we find them in Norway, New Zealand, and Tierra del Fuego. In most of the alpine glaciers of the northern hemisphere, there is evidence that in the period immediately preceding the present, they

extended farther down their valleys than at present.

The valley glacier has its beginning in the *snow field* of the higher portions of the mountains, which are the great feeding grounds (Fig. 67). Here the more level portions of the ground are permanently covered with snow, the accumulation of many winters. As this increases in depth, it is unable to remain on the steeper portions and drops

down the hillsides into the valleys, in the form of great snow avalanches. Here it begins a slow movement down the valleys, whose slopes are usually steep; and in the course of this movement, the snow becomes compacted into ice, and is transformed to the true moving glacier (Fig. 175). The rate of movement is exceedingly slow, and unless watched very carefully, is not noticeable. In a measure, its movement may be compared to that of river water, although this comparison is capable of being extended only in a very general way. It moves more rapidly in the central portion than on the margins, and, like water, it gradually moves down the grades. If the valley grade is regular, the surface of the ice is comparatively smooth, although it may here and there be creased by fissures or *crevasses* (Fig. 176). When the valley bottom is itself very irregular, and the slope changeable, the ice top may become transformed to a very rough surface, which is much broken and difficult to traverse, and which may be called an *ice fall*. By melting, as a result of the effect of the sun's rays, the surface of the glacier may have its irregularities increased; and in some cases the surface of a valley glacier is almost impassable (Fig. 177).

In the course of its movements down the valley, the glacier is engaged in the transportation of a certain amount



FIG. 176.

Crevasse in a glacier.

down the hillsides into the valleys, in the form of great snow avalanches. Here it begins a slow movement down the valleys, whose slopes are usually steep; and in the course of this movement, the snow becomes compacted into ice, and is transformed to the true moving glacier (Fig. 175). The rate of movement is exceedingly slow, and unless watched very carefully, is not noticeable. In a measure, its movement may be compared to that of river water, although this comparison is capable of being extended only in a very general way. It moves more rapidly in the central portion than on the margins, and, like water, it gradually moves down the grades. If the valley grade is regular, the surface of the ice is comparatively smooth, although it may here and there be creased by fissures or crevasses (Fig. 176). When the valley bottom is itself very irregular, and the slope changeable, the ice top may become transformed to a very rough surface, which is much broken and difficult to traverse, and which may be called an ice fall. By melting, as a result of the effect of the sun's rays, the surface of the glacier may have its irregularities increased; and in some cases the surface of a valley glacier is almost impassable (Fig. 177).

of rock material. Some of this is supplied from the valley sides, which are subjected to the action of weathering, and from which avalanches are not uncommon. As a result of this, the margin of the valley glacier is usually lined with rock fragments, to which accumulation the name *lateral moraine* is given. Where two valley glaciers unite, the



FIG. 177.

Glacier, Mt. Dana, California, showing rough surface and terminal moraine.

lateral moraines of one side of each glacier join and form a moraine in the center, known as the *medial moraine* (Plate 26). Some of this rock material escapes through the cracks to the bottom of the ice, and this is dragged along the bottom, giving to the ice a power which on a large scale is not unlike that of sandpaper. The moving ice drags these fragments over the bottom, and scours off other fragments



PLATE 26.

White glacier, Alaska, showing snow field, ice stream, and medial and lateral moraines.

from beneath. This material also is carried by the ice down the valley in the form of a *ground moraine* (Fig. 178). After a while, the glacier comes to an end at the place



FIG. 178.

Section of a glacier. M, medial; T, terminal; and G, ground moraines.

where the melting is equal to the supply of ice. Here much of the material that was brought on the

back of the ice, or beneath it, is deposited at the frontal margin, forming a *terminal moraine* (Figs. 177 and 178). The melting of the glacier furnishes water for a stream, which usually emerges from an *ice cave* (Fig. 179) at the front of the glacier, and passes down the valley as a muddy torrent, carrying with it some of the finer particles of morainal material. These are the most characteristic features of the valley glacier.

A rather peculiar modification of valley glaciers is found at the base of the Mt. St. Elias group of Alaska. In these mountains, there are many large and beautifully developed valley glaciers (Fig. 67), which, after reaching the foot of the mountains, extend toward the sea over a nearly



FIG. 179.

Ice cave at terminus of a glacier.

level plain. The slope of the plain is so slight, and the supply of ice so limited, that this part of the united glaciers is almost stagnant. There is hardly any perceptible movement; and near the margin, morainal material accumulates on the surface of the ice in such quantities as to completely bury it, forming a soil on its surface, upon which vegetation grows. We have on this, the Malaspina glacier, an instance of a well-developed forest, almost as luxuriant as some of those found in the temperate latitudes, but yet growing upon the back of a slowly moving glacier. A forest also extends up to the very base of the glacier (Fig. 180). This form of an ice sheet has been called a *piedmont* glacier, because it is developed at the foot of mountains.



FIG. 180.

Forest at the margin of Malaspina glacier,
Alaska.

(1) **Continental Glaciers.**—In the arctic and antarctic zones, the long winter, and the coolness of the summer, conspire to bring about extensive accumulations of snow and ice. As a result of this, some of the lands in these cold regions are covered with great sheets of ice; and these are generally in movement, from the central portion of the land mass, toward the sea. In Greenland, and on the Antarctic land, they are so large as to warrant the name continental, for they bury lands of continental extent. The Greenland glacier covers an area of over 500,000 square miles; and the Antarctic ice sheet is several times greater than this.

From the immense size of the icebergs that float away from the margin of the Antarctic ice sheet, we are certain that the depth of this glacier is greater than a mile; and

there is some reason for thinking that it is nearly two miles in depth, even at the margin, while in the interior the depth may be over five miles. But about the actual conditions existing on this sheet of ice we have very little knowledge, for this part of the world is almost entirely unexplored.

Within a few years, our information concerning the Greenland ice sheet has become very much increased. Several parties have examined it along the coast, and others have passed into the interior of the Greenland continent. Near



FIG. 181.

A nunatak rising above the Greenland ice sheet.

the margin, the ice extends down to the sea, sometimes as a solid wall, but usually in the form of tongues extending down the valleys. The ice front is often hundreds of feet in height, and when it extends into the ocean, bergs are fre-

quently detached and floated away. Passing from this rather irregular margin toward the interior, there is an area of rough ice which is difficult to traverse, and through which there are some projecting mountain peaks, known to the Greenlanders as *nunataks* (Fig. 181). These rise above the great ice field as the only parts of the land exposed to the air. Beyond a few miles from the coast, even these high mountain peaks disappear, and there is a great ice plateau,

generally over a mile above the sea, and in some cases having an elevation of about 10,000 feet.

Whatever the topography of Greenland may be, this immense sheet of ice entirely obscures it, and it probably covers a land which is mountainous in character. The surface of the ice in the interior is very smooth, and one may travel over it with considerable ease. The movement appears to be in all directions, from the central part toward the sea, as if the accumulation were greater in the interior than elsewhere. We can form no idea concerning the depth of this sheet of ice; but it is a moderate estimate to say that it is certainly several thousand feet in depth.

† **Icebergs.** — The cold Arctic winter causes the ocean

surface to become frozen; and the movement of the waters, resulting from the winds, currents, and tides, often breaks this ice and throws it into hummocks, so that during this season the Arctic water presents a rough ice surface. During the summer this partly or entirely breaks up, and the ice either melts or floats away. Added to this *floe ice*, are the icebergs which are derived from the margins of glaciers extend-

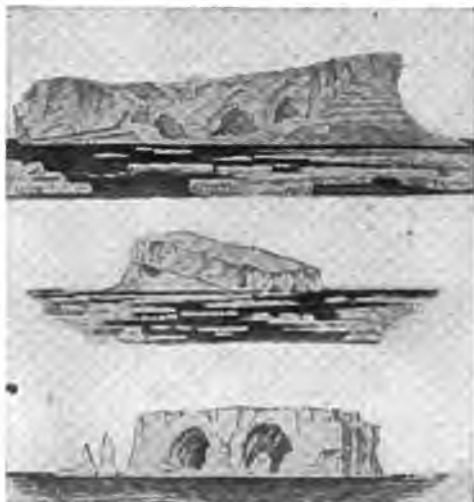


FIG. 182.

Icebergs in the Antarctic.

ing into the ocean (Fig. 182). As the ice moves into the sea, the buoyancy of the water causes it to break into fragments, which then drop into the ocean and drift away. Carried by the currents, these bergs may pass hundreds of miles from their source; and the Atlantic steamers not uncommonly encounter large icebergs that have been derived from the Greenland glaciers, while upon the shores of Newfoundland these are often stranded. An iceberg is mostly beneath the water; for, in a regularly formed ice block, there are 8.7 parts below the surface of the water for every one part that is above. Therefore if an iceberg of regular

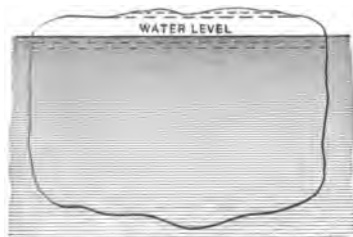


FIG. 183.

Diagram to show relative proportion of submerged ice in an iceberg.

form projects 100 feet into the air, there are 870 feet below the surface of the water (Fig. 183). In the case of irregular icebergs, this may not be true. The icebergs from the Greenland glacier often extend to a height of 100 or 200 feet; but those from the Antarctic ice sheet are sometimes several

hundred feet above the surface. Some bergs have been reported in the Antarctic, which had a height of over 500 or 600 feet above the water. One such berg extended to the height of 580 feet above the sea, and had a length of nearly three miles, so that the captain who saw it believed it to be an island. Other cases of icebergs with a length of over a mile, and a height of more than 500 feet, have been reported from this region. Such bergs measure about a mile from the top to the bottom which is beneath the sea.

Glacial Period: Area covered by Ice.—As was stated in the

last part of Chapter VII., the climatic conditions which we now find upon the earth, have not always been the same. The most recent and pronounced climatic changes, were those which caused the extension of arctic conditions into parts of the north temperate zone, and then, later, a change from this condition to the present temperate climate. As a



FIG. 184.

Glacial lakes and moraine, in a mountain valley not now occupied by a glacier.

result of these changes, the so-called glacial period was caused. This expressed itself in an increase in snow, both among the high mountains of the temperate zone, and in the higher latitudes. The valley glaciers of Switzerland, the Sierra Nevadas, and other mountains, were more extensive than at present, and mountain chains in which there are now no glaciers, then had their valleys filled with ice streams

(Fig. 184). But the most remarkable effect, was the production of ice sheets of thoroughly continental character, both in northwestern Europe and in northeastern America.

The entire north temperate zone does not seem to have been occupied by a glacier, but there appear to have been several large sheets, one set in Europe and another in America. It is not certain whether these were connected with the Greenland glaciers, but there seems reason to doubt whether there was such a connection. The extension of the



FIG. 185.

Approximate extension of the continental ice sheet.

glacier in the United States is shown on the map (Fig. 185). The entire region north of the line indicating the terminus of the ice, was covered with a glacier which appears to have resembled in most respects that which we now find on Greenland. Off the New England coast the ice entered the ocean, and from it icebergs were discharged; but in the interior, the ice front appears to have changed in position from time to time, now advancing, now retreating. Near the margin, where the country was mountainous, the higher hills projected above the ice in a manner similar to that

noticed along the margin of the Greenland glacier ; but in the interior of the ice sheet, the highest mountains appear to have been entirely buried. There is evidence that the White Mountains of New Hampshire, the Green Mountains of Vermont, and the Adirondacks of New York were all enveloped in this sheet of ice.

In Europe the conditions appear to have been similar, and the greater part of the British Isles, Scandinavia, Russia, and Germany, were covered with an ice sheet, or perhaps with several great glaciers moving from different centers. Recent studies seem to show that the Greenland ice did not have a much greater extension than at present, and that the region between America and Europe was not filled with ice. So far as we have evidence, there are no signs of extensive glaciation in northern Asia ; nor was there on the west coast of America, an ice sheet which in point of size would compare with that of eastern United States and Canada.

Why the climate changed, cannot be said ; and all that we can state definitely is, that we know that there was this change. We are not certain how long the ice remained, nor when it came, nor what its detailed history was. We do know, that before the glacial period, the climate was not frigid ; that the ice occupied the regions for a considerable length of time ; and that since then, the conditions have again become temperate. Studies of the rate of formation of such gorges as those of Niagara, and the Mississippi below the falls of St. Anthony, which began when the ice retreated, lead to the conclusion that the close of the glacial period was probably between 7000 and 10,000 years ago. From the geological standpoint, it was one of the most recent chapters in the history of the world.

Terminal Moraine.—The continental ice cap of the glacial period behaved very much as the Greenland ice sheet does

at present. Since no land projects above it, the Greenland glacier is not able to carry morainal material upon its surface; and the same appears to have been true of the continental glaciers of the United States and Europe. Like the Greenland glacier, each of these ice sheets moved from some central region, in case of eastern America apparently from the region of Hudson Bay or Labrador; and as they moved, they dragged rock material from northern towards southern regions. When the ice disappeared, much of this material was left, just as would be the case if the Greenland glacier should melt away. As in the Greenland and valley glaciers,



FIG. 186.

Boulder in the moraine at Cape Ann, Mass.

the front margin of the ice was a place of wastage, at which much material was accumulated in the form of a terminal moraine. One of the most distinct terminal moraines formed by the glacier of the United States, follows the heavily shaded line on the

map (Fig. 185). Other moraines are found north of this, marking stages of halting during the retreat of the ice.

Both in Europe and America, the glacier has produced a very pronounced effect upon the topography and the conditions of the land surface. There are many details which it would be impossible to consider in a work of this kind; but some of the more pronounced features may be mentioned. The terminal moraine is one of the most striking topographic forms resulting from glacial action. The topography is extraordinarily rough and irregular. There are hills and hummocks, enclosing valleys and pits, and all are thrown together in the most confused manner. The material com-

posing them is partly clay, partly gravel; and fragments of all sizes, from tiny bits of clay to large boulders (Fig. 186), are confusedly thrown together. Sometimes the surface of



FIG. 187.

The bear den moraine at Cape Ann, Mass., — a moraine whose surface is covered with boulders.

the moraine is strewn with large boulders (Fig. 187), and the morainal material is often 100 or 200 feet in depth, and sometimes even more.

Formation of Soil. — The ice contained much rock material derived from more northern regions; and when it ceased to move, and melted away, this was dropped at the place which it had reached. This ground moraine, which is commonly known as *till* or *boulder clay*, forms the soil of the greater part of the



FIG. 188.

Boulder-strewn till soil in Maine. Many boulders taken from the surface and built into walls.

country has been within the glacial limits. It is a clay through which boulders of various sizes are scattered (Fig. 189); and these boulders may often be recognized as fragments derived from hills to the north, while the finer particles are the result of the grinding action of the moving ice. For instance, in central New York many of the bould-



FIG. 189.

A limestone pebble covered with glacial scratches.

ers have come from the Canadian highlands. The scouring action that was in progress beneath the ice, is shown by the fact that these boulders and pebbles are finely scratched and grooved (Fig. 189); and the same is true of the bed rock beneath the soil. At times this till soil is several hundred feet in thickness, but usually its depth is only a few feet.

With the melting of the ice, streams were furnished both

with increased quantities of water, and with increased supplies of sediment; and these swollen rivers carried away from the ice a large part of the rock material which it bore, depositing some in their valleys, and spreading some of it over the lowlands. In part, at least, the prairie soil of some of the Central States appears to be due to this action of ice melting; and the *terraces* of many of the streams that extended from the ice front, have been derived in the same manner. Even a part of the delta of the Mississippi is probably built of sediment furnished by the melting ice, when the front of the glacier stretched across the head-water tributaries of this river.

Formation of Lakes.—Temporary lakes were formed by the ice, and in one or two cases these were of great size. They were commonly formed where the ice extended across streams that flowed toward the north, thus acting as a dam, and preventing them from taking their normal courses. While hundreds of such lakes were caused, one that formed in the valley of the Red River of the North was by far the largest and most remarkable of all. This lake, which has now disappeared, at one time covered an area of 110,000 square miles, being 15,000 square miles greater than the five Great Lakes combined. It covered the area included within the great wheat belt of the Red River valley, in Minnesota, North Dakota, and Manitoba; and Lakes Manitoba, Winnipeg, and Winnipegosis are descendants of this great lake, their combined area at present being but 12,500 square miles.

Lake Agassiz, as this great temporary water body is called, at places had a depth of 500 or 600 feet, and it outflowed southward, over the divide in Minnesota, entering the Minnesota River, and passing thence into the Mississippi. Thus by this great ice dam, drainage which now finds its escape

into the Arctic, was forced to flow in the opposite direction and enter the Gulf of Mexico. The proof of the existence of this great lake, is found partly in the presence of beaches and wave-cut cliffs, now standing high above the bottom of the valley, and partly in the great level plain of the Red River valley (Fig. 215). The levelness of this plain is due

to the deposit of sediment in the lake, the bottom being somewhat like that of Lake Erie.

Among the other striking effects of the glacial period, was the formation of many of the existing lakes. In Minnesota there are fully 10,000 lakes and ponds which were caused by the glacier; and throughout the Northern States, there are scores of thousands of glacial lakes (Fig. 190). Before the ice occupied the country, the rivers had well-established drainage lines, and pronounced



FIG. 190.

Map of a part of Massachusetts, showing abundance of lakes caused by glacial conditions. Shaded areas represent lakes.

valleys existed. For a time the ice occupied these and prevented them from being used as drainage ways. When the glacier melted, it deposited the rock materials which it was carrying, and deposited these regardless of the

pre-glacial drainage lines. Sometimes great masses were dumped across a stream channel, while in other cases, as for instance upon plains, the glacial materials were deposited irregularly, so that basins were formed on the drift-covered surface. Also, during its movement, the ice appears to have deepened some valleys more than others, and some parts of valleys more than other portions, thus forming *rock basins*. All of these basins, whatever their cause, were filled with standing water when the ice melted, and were thus transformed to lakes. When the glacier disappeared, the surface of the land was dotted with lakes of various sizes and depths, and many of them still remain (Figs. 168 and 190), although some of the smaller have been destroyed, or transformed to swamps (Fig. 172), either by filling or by cutting down the gravel barrier. Even the Great Lakes appear to owe their origin, in large part, if not entirely, to the action of the ice; and the same is true of the Finger Lakes of central New York, of Lake Champlain, and indeed of practically all the lakes north of the terminal moraine.

Formation of Waterfalls.—As a result of the same cause, the streams which began to flow after the ice disappeared, were often on one side of their pre-glacial channels. Some were entirely turned out of their valleys and forced to form new ones. Others were only turned aside for short distances; and in some extreme cases, they were actually caused to flow over old divides, in an opposite direction from that which they had pursued before the beginning of the glacial period. The time that has elapsed since the close of the glacial period is very brief considered from the geological standpoint; and for this reason, the streams that have been obliged to cut new valleys have succeeded in producing only very narrow gorges (Frontispiece, and Figs. 133 and 191). The action of cutting in the channel has exceeded that of weathering,

and these being subject to narrow, steep-sided, ~~valleys~~
 in places in which ~~valleys~~ are common. We find
 evidence of these post-glacial valleys in almost every
 part of the region occupied by the ice. Side by side we may
 find an old pre-glacial valley with its normal gentle ~~sloping~~
 sides and the narrow, steep-sided channel of post-glacial
 origin. These may often be found



FIG. 191.

A view in Watkins Glen, New
 York, a post-glacial gorge.

in the same valley. The stream is a
 part of the drainage occupying the
 pre-glacial trough and in places be-
 long to these post-glacial trenches.

So generalised has been the effect
 of the ice in the production of lakes
 and waterfalls, that with a fair de-
 gree of accuracy one could map the
 southward extension of the ice sheet
 by merely drawing a line across the
 country, separating the region of
 abundant lakes, waterfalls and
 gorges, from the regions to the
 south, in which these features are
 rare, if not entirely absent. This
 is particularly well illustrated in
 New Jersey where the line runs in
 a westerly direction; and one can
 see the point well brought out by
 examining a map of a part of Massachusetts, New York,
 Wisconsin, Minnesota, etc., and comparing it with a similar
 map of Kentucky, Virginia, etc. The entire drainage sys-
 tem of the land that was covered by the ice has been rejuve-
 nated, and the details of topography have often been en-
 tirely altered. The great features of hills and valleys are
 practically the same as those which existed before the ice

came; but many of the minor details of sculpturing and of filling are the result of glacial or post-glacial changes.

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For a statement of **CROLL'S HYPOTHESIS** for the cause of the glacial period, see his "Climate and Time," referred to at the end of Chapter VII.

CHAPTER XVIII.

THE COAST LINE.

General Statement.—The seacoast is a place of very active change, for here a very slight movement in the land registers itself distinctly in the outline of the shore. Materials are being brought by various agents and deposited in the sea; and along the shore line, there are ever-acting forces which tend to wear back the coast and change the outline. The agents of destruction are mainly those of waves and associated currents; and the materials removed from the coast by wind waves, are taken away and distributed over the sea bottom by wind, tidal and ocean currents. There is very little difference between the coast line features of the sea and those of lakes. Waves repeat on the lake shores nearly all the features of the ocean shore line (compare Fig. 192 with 212, and 200 with 213), though usually with less intense development. Cliffs and headlands are less pronounced, beaches are less extensive, the action of tides is absent, and in many minor ways the lake shore lines differ from those of the sea; but in general features there is a close resemblance.



FIG. 192.

A cliff at Cape Cod, Mass., showing destructive action of waves.

Effect of Elevation. — Since the sea bottom is mostly level, and since deposits of unconsolidated sediment are spread over it (see pages 157 and 164), an elevation of the bottom above sea level, usually produces a regular coast line, and the materials composing the coast are soft clays or sands. There is a general absence of projecting capes, promontories, islands, and the smaller irregularities of the coast. The kind of shore line that is produced by this cause, is well illustrated on the coast of Texas (Fig. 194), although here there have been some irregularities introduced by other causes. Great sandy beaches, extending for many miles, separate the dry land from the sea; there are no rocks and no high cliffs, but sand everywhere.

Effect of Depression. — The effect of depression of the land, or, what would amount to the same thing, the elevation of the sea level, produces just the opposite result. Instead of causing a regular coast line, it produces marked irregularities. If the student could imagine the sea rising to the level of the place upon which he lives, he would have some idea of the coast irregularities that would result from a depression of the land. The sea would rise to the perfectly horizontal line, and would extend up every valley to the supposed level. Some low hills would be entirely submerged, while others that rose to heights slightly above the new sea level, would form islands. Projecting hills would be transformed to promontories or capes, and the stream valleys would either become estuaries or bays (Fig. 193).

In many parts of the world, the last change at present distinctly registered along the coast, has been that of submergence of the land; and in such places we find an exact reproduction of the conditions imagined. If one examines the coast of Maine, as represented upon a good map, it is readily seen that the numerous bays and islands are nothing but land-

made forms which have been partly submerged beneath the sea. Figure 211, representing a part of this coast, is a particularly good illustration of these irregularities.



FIG. 193.

Coast of Mt. Desert, Maine, showing effect of submergence.

The coast of northern Europe illustrates the same type; and on the American coast, not merely does Maine furnish an illustration, but from the Arctic to Florida, there are abundant instances of this same effect of land movement. Chesapeake Bay (Plate 24) is a land-made valley into which the sea has entered by submer-

gence; and the tributaries to this bay are river valleys also partly drowned by the sea. Those who dwell upon these coasts find it impossible to say where the river ends and the sea begins.

Thus elevation tends to produce smooth coasts, while depression introduces irregularities; and since the crust of the earth is in almost constant movement, either in one or the other of these ways, we find that the general outline of the seacoast is usually either very irregular or very smooth. In this connection one may well compare the northeastern coast of the United States, where the land has recently been lowered, with the western coast of South America, where the land is rising.

(c) **Effect of Sediment.** — The waves and currents in the sea, tend to distribute over the sea bottom all mechanical fragments brought to them from the land, and to form sedimentary deposits with them. Generally the sea is able to remove

these materials and to deposit them away from the coast; but in some cases, the amount of sediment brought exceeds the ability of the oceanic agents to remove it. This is particularly the case at the mouths of large rivers where deltas are being formed. Thus opposite the mouth of the Mississippi, the coast is rapidly growing outward in the form of a delta (Fig. 153), and the same is true of the Nile, and many other large rivers of the world. Even where this is not happening, the amount of sediment brought to the sea may so far exceed the power of the waves to remove it, that the coast grows outward. Very nearly the entire coast, from Sandy Hook to the northern boundary of

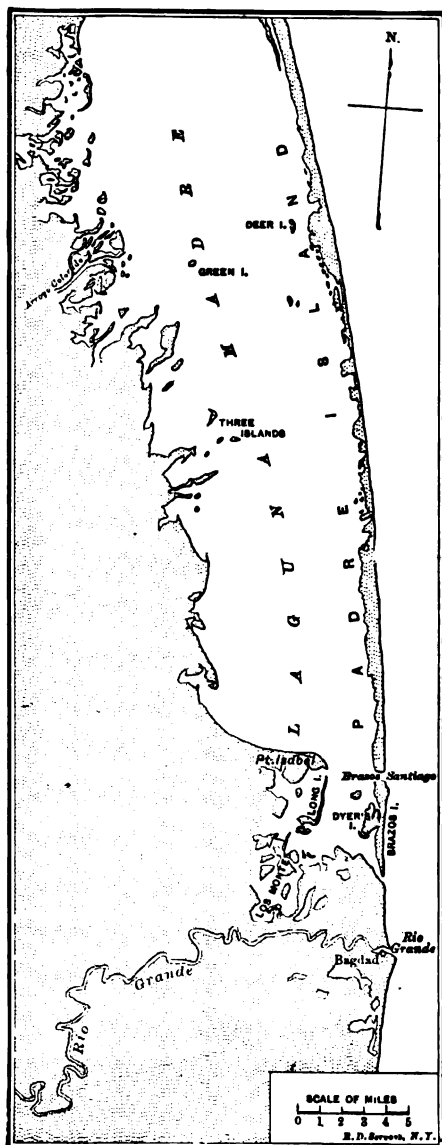


FIG. 194.

Part of an extensive sand bar on the Texas coast.

Florida, is being built outward by the accumulation of sediment that the waves have not been able to distribute over the sea bottom. This sediment is brought to the sea by the rivers, and is piled by the waves into sand banks and bars; and these bars extend as long islands parallel to the coast (Fig. 194), being separated from the mainland by shallow bodies of water in which salt marshes are often present.

Effect of Waves and Currents. — On exposed coasts, the

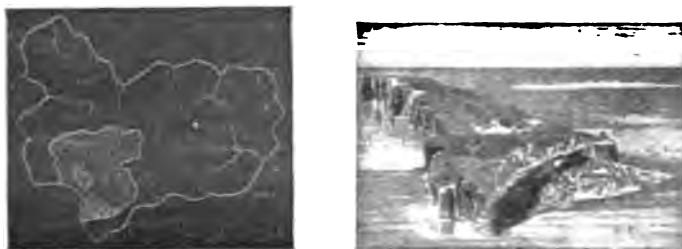


FIG. 195.

View of the island of Heligoland, and map showing how rapidly it is being destroyed. Outside line shows boundary in the year 800, when the circumference was 120 miles; shaded area, boundary in 1300 (circumference, 45 miles). Innermost area, 8 miles in circumference.

ocean waves are constantly beating with such force that even the very hardest of rocks are worn away. On the European shore, within historic times, this destruction by the waves, combined with the action of the tides in removing the fragments, has caused the coast to retreat, often for distances of several miles. Places that a few hundred years ago were at a considerable distance from the coast, are now either entirely destroyed, or else are nearer the sea than formerly. On parts of the coast of England, the sea cliffs are being worn back at the rate of five or six feet a year; and

it has been estimated that, on a part of the coast of Yorkshire, the shore line has been worn back a distance of two miles since the time of the Norman Conquest. Many similar cases might be introduced in illustration of this wearing back of the coast line (Fig. 195). On the American coast, we have no remarkable instances of rapid change; but still there is every reason for believing that the shores, in certain exposed places, are actually being worn back at a perceptible rate.



FIG. 196.
Lake spit.

At the southern end of Martha's Vineyard, the cliffs of Gay Head are thus retreating.

While in some places the action of waves and currents



FIG. 197.
Hook, Lake Michigan.

is destroying the coasts, in others it is engaged in building them up. This was stated in the preceding section; and not only is it true in that large way, but also in a small way. The tidal currents in the vicinity of

Nantucket and Martha's Vineyard, on the south side of Massachusetts, are moving the sands in such a way that bars are being formed, and are almost constantly changing in

and the general. In some places where the character of the surface is irregular, particularly where it is high and bold, the waves are more (Fig. 197). Some may also be formed by the action of the wind on the surface of the water (Fig. 198).

Another kind of wave is formed where there are rocks or reefs, and a very marked difference is the action of these rocks upon the waves. On exposed rocks the waves are high and the action of the waves is very violent and the rocks are in some



FIG. 198.

Sea cave in a well-jointed granite rock, Cape Ann, Mass.

places is liable to be very precipitous. In enclosed or partially enclosed estuaries and bays, the wind waves are of very little importance, and the changes of the coast line are relatively moderate. In harbors, for instance, the wind waves are producing almost no change in the coast. Such enclosed areas are usually the seat of deposition, instead of places in which destructive action is in progress.

Great difference also results with variations in the kind of rock which makes the coast. The waves find it very easy

to cut their way into soft sand and clay, while hard granite rocks resist their action. In the hard massive rocks, particularly if these are exposed to the action of the oceanic waves, there are produced cliffs of great size and ruggedness. Against the base of these, the waves dash with violence; and along the line at which they are wearing, *sea caves* are often cut in the rock (Fig. 198). The cliff is undermined along this line of wave action; and, by the dropping down of fragments, it tends to remain in the form of a cliff. Where the rocks of the coast are soft, these very precipitous slopes



FIG. 199.

Indentation on the coast of Cape Ann, Mass., where the waves are removing a soft dike rock which crosses the hard granite.



FIG. 200.

Pond enclosed behind a beach which is built across a small bay, Cape Ann, Mass.

cannot be maintained; and where a hard rock is crossed by a less durable one, the coast is rendered irregular (Fig. 199).

While these peculiarities of coast line may be found developed in many parts of the earth, the tendency of the



FIG. 201.

A crescent-shaped beach, Cape Ann, Mass.

waves and currents is to render the coast line always more regular. Materials are worn by the waves from the headlands, and drifted into the bays, which they tend to fill. In the course of time, if nothing interferes, this material is formed as a bar across the mouth of the

bays, and later is built into a beach, which rises above the surface of the water, enclosing the bay as a pond behind the beach barrier (Figs. 200 and 213). The material built into the beach is usually deposited in the form of segments of a circle, concave toward the sea, giving the well-known crescent-shaped beach of the seashore (Fig. 201). The headlands form the two ends of the segments, and the material on the beach grades from coarse pebbles (Fig. 202) near



FIG. 202.

Boulders worn from a headland by ocean waves.

the headlands, to fine sand in the central part of the beach. The beach is a great mill in which rock fragments are being ground by the waves and removed toward the sea (Fig. 203). Sometimes these beaches are of great extent; but almost

always their typical form is that of a part of a circle, the curve usually being a beautifully swinging curve; and there is a rhythm which appears to bear a relation to wave force and direction, and sediment supply.

Effect of Plants.—It is difficult to estimate the importance of the seaweeds which cling to the rocky coasts. They form an elastic mat which protects the rock from the beating of the waves (Fig. 204); and upon their own



FIG. 203.

A rocky beach on the exposed coast of Cape Ann, Mass.

structure, which is capable of being replaced if damaged, they receive the destructive blows of the waves. Along the rocky coast of New England, the seaweeds cover the rocks from near the line of mid-tide to a depth of several feet below the lowest tide, which is the zone where the waves are most active. If it were not for this covering, these rocky coasts would certainly be worn back with much greater rapidity than at present.

Another way in which plants are active along the shore



FIG. 204.

Mat of seaweed between tides, Cape Ann, Mass.

line, is in the actual construction of land. On the Florida coast there is a peculiar type of tree, the mangrove, which has the remarkable habit of growing with its roots in salt



FIG. 205.

A mangrove swamp.

water. The roots extend into the sea in a network, raising the tree trunk above the sea level, as if it were on stilts (Fig. 205); and these root-like branches of the tree encroach upon the sea. By this growth of the mangrove, seacoast swamps are produced in the shallow waters near the tropics, and in this way the coast line is built outward. As the trees die,



FIG. 206.

A salt marsh partly filling an estuary, Cape Ann, Mass.

their fragments accumulate in the shallow water; and between the roots sediment is entangled, so that little by little the land is actually built up and the salt water displaced by swamp.

Even more important than the mangrove, is the action of some of the grasses which grow in the shallow water of pro-

tected bays and estuaries (Fig. 206). These salt marsh and eel grasses are able to live where the waves are not too violent; and by their growth and death, as well as by their action in entangling and causing the deposit of sediment, they are important aids in the filling of these shallow bays. Along the eastern coast of the United States there are thousands of square miles of salt marsh which are in large part the result of this action of vegetation. The marsh is built up to a level just above that of the highest tide; and along the coast of this region, there is every gradation between dry land and the shallow water of enclosed bays, upon which the marine vegetation is just beginning to encroach. One sees it in almost every bay and estuary, from the Carolinas northward to the boundary of the country. There are vast areas of this salt marsh in the lagoons behind the bars which are formed along the southern coast.

Effect of Animals. — There are many ways in which animals are changing the form of the coast line, by far the most important being the action of coral animals. These creatures are able to live only under certain very favorable conditions. The water must be warm, and the temperature must always remain above 68°. It must also be clear and free from sediment. The animals cannot live in depths greater than 100 feet, nor can they thrive unless there is a free exposure to currents and waves, which bring food to them. Therefore we do not find that the coasts of the tropical regions are always made by corals.

Where conditions are favorable, corals thrive in a marvelous manner (Figs. 79 and 207). They live in an abundance that is hardly equaled by any of the other marine animals. Each individual builds a skeleton of carbonate of lime, and these, combining, form a coral mass, which upon the death of the animals, is left behind to enter into the formation of a

limestone rock. The corals grow along the coast, forming large reefs; and at times they produce reefs at a considerable distance from the shore, which are then known as *barrier reefs*. The Great Barrier Reef of Australia extends along the coast, with some interruption, for a distance of 1000 miles; and at times its distance is 60 miles from the shore, being the most extensive growth of coral in any single region in the world. Its



FIG. 207.

A coral reef on the Australian coast.

width at the surface is rarely more than one or two miles.

At times the coral builds isolated islets, which are often known as *keys*, and which are so well illustrated by the keys

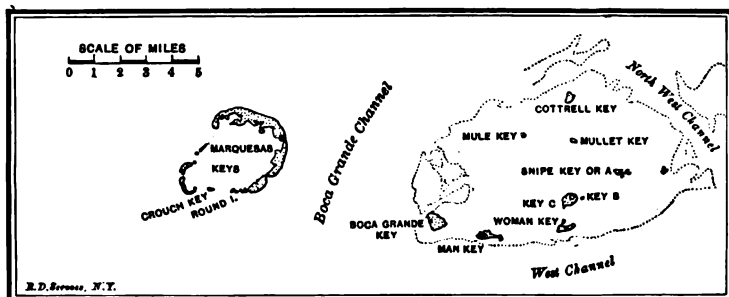


FIG. 208.

Atoll-like keys on the Florida coast.

at the southern end of Florida (Fig. 208). In the mid-ocean, particularly in the South Pacific, the coral growth forms ring-like islands, which are known as *atolls* (Fig. 209). Sometimes these are nearly perfect rings, enclosing an area of water which is connected with the sea by a small opening. The atoll rises above the level of the sea to a height sufficient for the growth of trees, and many of these islands are inhabited by man. The reason for their elevation above the sea is the washing action of the waves, combined with the



FIG. 209.

An atoll in the South Pacific.

blowing of the wind, which drifts the coral sand into mounds. On all of these reefs, corals are still living and growing where exposed to the action of the waves and currents which are bringing food to them. It is found that the coral reefs are better developed on coasts which are exposed to the oceanic currents of tropical origin. As is so well illustrated in the Bermuda Islands, which are in latitude 32° N., corals may be developed where these currents extend their warmth into latitudes well beyond the tropics.

The cause for atolls is at present in dispute, and it does not seem desirable to consider the question as to which explanation is correct. The one which has been before us for the longest time (having been proposed by Darwin), and is accepted by many geologists, is that the atolls are nothing more than reefs which once surrounded volcanoes that have since disappeared by submergence (Fig. 210). As the cone sank beneath the water, the corals built the reef higher and higher, so that even after the cone had entirely disappeared, its position was indicated by the ring-like reef. Certainly this seems to be a true explanation for some atoll reefs; but for others, another explanation is very likely necessary. The great barrier and fringing reefs are merely formed by the growth of the coral along or near the coast line.

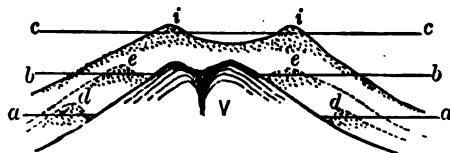


FIG. 210.

Diagram to illustrate one explanation of the origin of atolls. V, volcanic cone; aa, bb, cc, successive levels of the sea; dd, ee, and ii showing corresponding condition of the reef, finally producing the atoll ii when the volcano was entirely submerged.

Changes in Coast Form. — With change in the conditions, a coast may assume entirely different characteristics. If, for instance, the clear waters of some coral coasts are for any reason changed to muddy water, coral life is driven out, and the muddy or sandy shore takes its place. If land is elevated, or if it is depressed, the form of the coast is very greatly changed. The agents of denudation are always at work tending to alter the coast form. Therefore the shore line which we know at present, is merely a temporary feature, merely the stage which has been reached at the present time; and it is far from the condition which has existed in

the past, and probably from the condition which will exist in the future. In imagination we are able to look back to the time when the eastern coast of the United States had not its present irregularity; and by geological evidence we are also certain that but a short time ago Florida was not present as a peninsula. The delta of the Mississippi is a growth of very recent date; and preceding its formation an estuary extended up the valley of the Mississippi, at least as far as Arkansas.

Our knowledge of the geology of the coast line is not sufficiently detailed to allow us to study all the changes that are going on; but any one who dwells by the coast, will be able to see that there are some changes now in progress. A visit to the seacoast in time of storm, or indeed to the lake shore, will convince any one that there are changes in progress, which, as a result of the repetition of this action through scores of years, must produce perceptible changes.

Islands. — There is a very great variation in the size of oceanic islands, in the distance from the shore, in the form, and in origin. It is quite customary to speak of two classes of islands: oceanic and continental, the oceanic being those which occur far from the land. These *oceanic* islands are generally of three classes: (1) those that are formed by volcanoes, (2) those that are produced by the folding of mountains, and (3) the mid-ocean coral reefs. Generally they are small, and they often occur in chains, as if they represented tops of mountain peaks along some ridge that is partly beneath the ocean. In some instances, soundings have shown that this is actually the case.

Near the coasts of continents we have the same kinds of islands. The Japanese archipelago is apparently a mountain chain which is now in process of being formed. In the Mediterranean, among the West Indies, and elsewhere, there

are many instances of volcanic peaks which form islands not far from the coast; but probably nine out of ten of the islands of the world have resulted from causes other than these. Most of the islands are derived either from the submergence of the land (Fig. 211), or from the building up

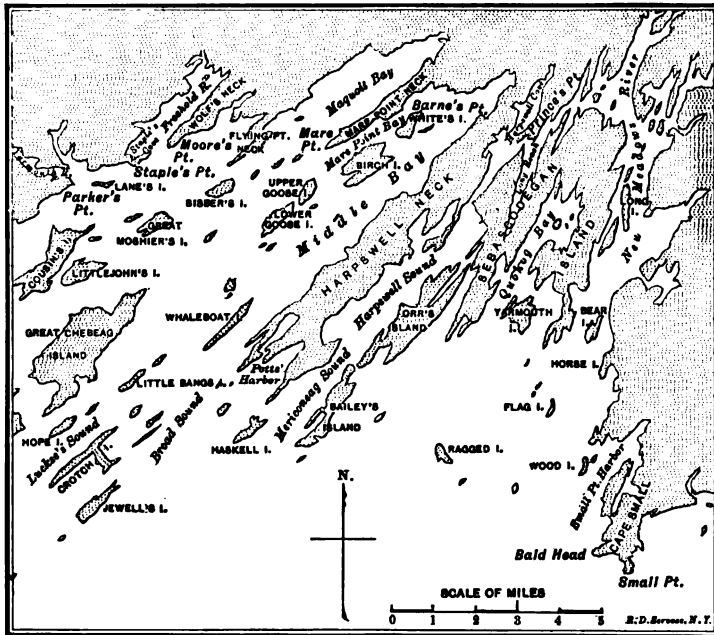


Fig. 211.

The islands, capes, and promontories of Casco Bay, Me.

of the coast line by wave action (Fig. 194). As has been stated, the waves throw up bars in favorable places, the wind gathers the sand and blows it into sand dunes, and islands of this origin are found in abundance along many coasts. South of Cape Hatteras there is a line of such islands, which are due partly to wave and partly to wind

action, and which stretch along the coast parallel to the mainland, and but a short distance from it.

When an irregular coast is lowered, the sea rises around the hills, forming islands. This is excellently illustrated on the coast of Maine (Fig. 211), where the thousands of islands and islets are in most instances the direct result of the partial lowering of hilly land beneath the sea level. There are some minor ways in which islands are produced, but these are by far the most important.

Being surrounded entirely by water, islands are peculiarly liable to destruction by wave action (Fig. 195). They are open to attack from every side, and if they happen to be in the ocean far from the land, they may be very rapidly destroyed. Even extensive volcanoes in the mid-ocean are quickly worn away as soon as the volcanic fires have ceased to add material in place of that which the sea removes. Among the Hawaiian Islands, the smaller islands, which were formed by volcanoes now extinct, are rapidly being destroyed; and the same is noticed throughout the Pacific, as well as among the volcanic islands of the Atlantic (Fig. 125). A volcano formed in the Mediterranean, in 1831, and known as Graham's Island, reached a height of 200 feet, with a circumference of three miles; but in the course of a few years it was entirely destroyed by wave action.

Promontories. — Capes and promontories belong to the same class of seashore forms, the difference being merely in size. They are produced in several ways. Some of the largest promontories are parts of mountain folds in the sea. Others are areas of hard rock which have resisted the agents of denudation and formed highlands, which, when a submergence of the land took place, remained above sea level, while the lower, neighboring parts of the land were submerged. Labrador and Nova Scotia illustrate this.

By far the greater number of capes are a result of this kind of submergence of land (Fig. 211). The peninsula of Florida owes its existence, in part at least, to the action of corals, which have built the southern half. The warm Gulf Stream, which bathes this coast, has brought food to the coral animals, and these have built reefs. In the vicinity of Key West the peninsula of Florida is still growing south-



FIG. 212.

A bluff cut in clay, on the Lake Michigan shore.

ward, the keys being merely small parts of a submarine plateau which are above the sea. Some small capes are caused by the building out of the land through the deposit of sediment. Sandy Hook is an illustration of this, and many of the hooks and spits of sandy coasts are of the same origin (Figs. 196 and 197).

Lake Shores. — On the shores of lakes we have instances of changes due to wave action, of cliffs formed by the under-

cutting of waves (Fig. 212), of the building of bars and hooks (Fig. 197), of the formation of beaches (Fig. 213), and indeed of nearly all the phenomena of the seashore. Since many lakes are nothing but river valleys that have been dammed through some agency, both islands and capes are often produced. These occur where the necessary irregularities existed on the side of the valley which has



FIG. 213.

A lagoon enclosed behind a beach barrier on the shore of Lake Michigan.

been filled with water. Where there were tributaries to the stream which has been transformed to a lake, the lake water enters in the form of a bay; and the hillside bordering this bay extends into the

lake as a cape. Sometimes there are hundreds of islands in the lake waters. The Thousand Islands, at the outlet of Ontario, are the tops of low hills, the sides of which are submerged beneath the lake waters.

In the lakes there is usually less violent action than on the seashore, partly because the waves do not rise to the height of the true ocean wave, and partly because the tide action is absent. The shores of most of the smaller lakes bear a closer resemblance to those of the partly enclosed harbors and bays of the seacoast, than they do to the exposed ocean coasts. But except in intensity of development, there is little difference between lake shores and seacoasts.

Fossil Shore Lines. — Coast lines are sometimes abandoned,

and may then be found on the dry land. This happens when the land on the seashore rises, or when for any reason a lake disappears. These shore lines have all the features of those now forming in the sea or lake. There are fossil beaches (Fig. 170), bars, spits, hooks, wave-cut cliffs, etc.; and immediately after their abandonment by the waves their features are very distinct; but in a short time they begin to crumble away under the action of denudation, and before long no sign is left to tell of the change. Such ancient shore lines on the coast of New England and Labrador, tell of a recent submergence of the land; and the shore lines south of the Great Lakes, tell us that they once covered a considerable area of country south of their present site.

REFERENCE BOOKS.

Much of interest is found in Gilbert's "Lake Bonneville," referred to at the end of Chapter XVI. A special paper on shore lines, by the same author, is found in the Fifth Annual Report U. S. Geological Survey, Washington, 1885.

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CHAPTER XIX.

PLATEAUS AND MOUNTAINS.

Plateaus.—A plateau is a level-topped area at a considerable elevation above the sea. In many respects it resembles a plain (Figs. 214 and 215), but usually it is not

so level; and the ordinary distinction between plains and plateaus is based upon elevation.

Both are relatively level areas; and both plains and plateaus are usually



FIG. 214.

Pecos River valley, southern New Mexico.

composed of sedimentary rocks in a nearly horizontal position.

Plateaus are generally associated with mountains, and most mountains rise above a basal platform which is a true plateau. Thus at the eastern base of the Rocky Mountains, the plateau of the Mississippi valley ascends to the very mountain base, while on the western side there is the extensive interior plateau of the Great Basin. In nearly



FIG. 215.

Plain in the valley of the Red River of the North.

every continent there are large plateau areas, but nowhere is this form of topography better developed than in the central part of Asia, north of the Himalayas, where for thousands of square miles the plateau rises to an elevation of several thousand feet. A portion of the Indian plateau region, as well as a part of the plateau of the Rocky Mountain area, is covered with an extensive series of lava flows which have been sent to the surface through great fissures. The lava-capped plateau of the Deccan has an area of 200,000 square miles, and that of the Snake River valley of Idaho also covers an immense area, with a depth in places greater than 3000 feet.

Since they are in association with mountains, these plateaus are very liable to be arid. Many of the interior deserts between mountain ranges are real plateaus, as is so well illus-

trated in the western part of our own country. Among the various mountains of the western half of the continent, the prevailing condition is that of arid plateaus broken by occasional mountain ranges; and the conditions of dryness and absence of forest-covering, exist also on the plateau east of the Rocky Mountains. This plateau region is usually spoken of as the *Plains* of the Far West. In the general levelness of the surface, and also in the absence of forest, it resembles the *prairies* east of the Mississippi. But in the case of the prairie, the forest is not absent because of dryness, while this is the cause for its absence in the so-called Plains.



FIG. 216.

Taos Mountains, New Mexico, rising above an extensive plateau.

Since plateaus are elevated above the general level of the country, they are often very deeply carved by river erosion. Some of the most remarkable cases of deep, narrow river valleys are found among high plateaus. Nowhere is this better illustrated than in the high plateau of Utah and Arizona, through which is cut the remarkable cañon of the Colorado (Fig. 142 and Plate 28). In this respect also, there is a difference between plateaus and low plains; for



FIG. 217.

The plateau near the Colorado River.

the latter are not crossed by deep valleys, because their surface is usually not far above the level of the sea.

As is so strikingly shown in the cañon of the Colorado, the ruggedness of the river valley formed among plateaus, depends in no small degree upon the climatic conditions. The climate is so dry that the agents of weathering are not very important; and consequently the main work of sculpturing is done by the river itself. This causes a deep, angular trench, whose angularity is preserved because the rocks which border

the valley are not rapidly melted away under the action of rain and frost. As a result of this peculiarity, the characteristic topography of the plateau in an arid region, is that of occasional level stretches with steeply sloping boundaries (Figs. 142 and 217). The country is often cut into a series of terraces, one step above and beyond another. In the western part of this country, the level-topped sections of the plateau have been given the name of *mesa*, which means table; and when the level-topped sections are small, they are called *buttes* (Figs. 218 and 257).

Mountains: *Characteristics of Mountains.* —

Popularly considered, a mountain is any unusual elevation; and upon the plains of Texas, an elevation of 100 or 200 feet passes as a mountain, while in a thoroughly mountainous district, elevations of 1000 or 2000 feet are known as hills. We shall accept this common usage of the



FIG. 218.

Butte in New Mexico.

term mountains; but it will be pointed out that there are various kinds, derived in a variety of ways. By far the greater number of mountains, and certainly the most pronounced in the world, are the direct result of folding of the earth's crust, in nearly all cases combined with a great amount of destructive action of denudation. Along certain lines, the rocks of the crust are folded and broken into great ridges and chains, which in some cases extend from one end of a continent to another. Indeed, in the American continents there is practically one continuous set of rock folds,

from the southern end of South America to the northern part of Alaska.

A set of rock folds forming a great mountain series is generally known as a *system*. The Rockies form a system of mountains, and several systems combined form a *cordillera* (Fig. 129). This is illustrated in the western part of this country, which is crossed not only by the Rocky Mountains,



FIG. 219.

A talus slope at the base of a mountain ridge. (Elk Mountains, Colorado.)

but by the Basin Ranges, the Sierra Nevadas, and the Coast Ranges. When we examine any single mountain system, as, for instance, that of the Rockies, we find it to be composed of various parts. There are individual *ranges* among these mountains, and any single range is also found to be composed of separate parts, to which the name *ridges* (Fig. 219) may be given. In all of these cases, the striking peculiar-

ilarity is that the length of the mountains greatly exceeds both the width and the height. The cordillera and the system may extend for a thousand or more miles; the range may extend for a distance of more than a hundred miles; but the ridge is usually only a few miles, or at most a few score of miles, in extent.

There are prominent parts of mountains which do not have this characteristic of the ridge, and these are spoken of as *peaks* (Fig. 220). In nearly all cases the real mountain peak is merely a portion of a ridge or chain, which for some reason stands up higher than the surrounding parts. The usual cause for this greater elevation of one portion, is the



FIG. 220.

Matterhorn, a Swiss mountain peak.

presence of some hard rock which resists weathering. While mountains are forming, and after they have been formed, they are subjected to the agents of denudation, which tend to wear them away; and in this process of destruction, the harder rocks are left higher than the softer ones. In looking among the more pronounced mountain peaks of the world, we find that in most cases these are made of some particularly durable rock. Pike's Peak is made of granite;

the Matterhorn (Fig. 220) of the Alps is composed of a similar hard crystalline rock, and the White Mountains of New Hampshire, the peaks of the Adirondacks, etc., have the same characteristic. This is the typical mountain peak, a form resulting partly from the folding of the rocks during the formation of the mountains, partly from the differences in the hardness of rock, and partly from denudation. In the longitudinal parts of mountains, the fold is the most prominent factor; in these more nearly circular portions, the factor of prominence is rather that of denudation.

There are other forms of mountain peaks in which rock folding does not enter as a prominent cause. The most abundant of these are the volcanic peaks whose origin and characteristics are discussed in the next chapter. In many parts of the world, particularly on plateaus, there is a form of elevation often called a mountain, which is the result merely of denudation acting upon strata whose position is nearly horizontal. There has been no folding, and no disturbance of the rocks other than that of elevation; but hills or peaks have been cut out by erosion, and these now stand above the general level of the country. In the western part of the United States they are often known as buttes. By some they are called hills of circumdenudation, because all around the elevated portion the rocks have been cut away (Figs. 218 and 257).

Next in prominence to the elevations of the mountains are the depressions. Between the ridges, systems, and peaks, there are valleys; and these have quite distinct characteristics. Between systems, and really forming a natural part of cordilleras, there are often great valleys, sometimes hundreds of miles in width and length, to which the name *interior basin* is generally given. They are great plateau areas between mountain walls, and they are usually more or less

broken by mountain ridges. Sometimes, in part of their area, there is drainage to the sea; but very often, and as a characteristic feature, a part of the drainage finds its way into these great troughs and does not escape to the sea, but is returned to the air by evaporation.

The Great Basin of the United States has an area of over 200,000 square miles; but notwithstanding the great size of



FIG. 221.

A mountain park (Baker's).

the basins of interior drainage on this continent, these form but 3.2 per cent of the total continental area. In Australia nearly 52 per cent of the area is in the condition of interior drainage, while 31 per cent of Africa is in the same condition, and 28 per cent of the continental mass of Eurasia is an enclosed basin. The Sahara interior basin is 16 times as large as our Great Basin, and the interior basin region of Asia occupies an area 23 times as great as that of the west.

Between mountain ridges and chains, there are often longitudinal valleys of considerable size, extending parallel to the chains between which they occur. These are among the striking features of mountains, and they are generally occupied by streams which are evidently too small to have carved such immense valleys. When the rock structure is studied, it is evident that these valleys represent either down-folded portions of the crust, or else portions



FIG. 222.

A mountain gorge in the high Andes of Peru.

that have been broken or faulted down. Where these valleys occur between peaks and ridges, forming amphitheaters among the mountains, they produce a characteristic valley, which among the Rocky Mountains is given the name of *park* (Fig. 221).

Occasionally the streams have carved mountain gorges, and even in some cases have cut entirely across the ridges, forming valleys which are characterized by remarkably steep-sided gorges (Fig. 144). They furnish some of the most

striking bits of mountain scenery, and in traveling across a mountain ridge upon a railroad, one is often carried through these gorges, which furnish the sole means of easy passage for the railroad (Figs. 134 and 222). Low points in mountain ridges are known as *passes*. Sometimes these are merely parts of the mountain which were not folded so high as other portions; but in many cases they are valleys



FIG. 223.

Mount of the Holy Cross, Colorado — above the timber line.

at the headwaters of streams. Two streams head together in a mountain ridge, and these lower the ridge at this point, producing a gap, which is usually taken advantage of as a means of passage across the mountains.

Mountains in their best development are extraordinarily rugged. They rise in a series of slopes, sometimes moderate, but at other times very precipitous. They are cut by

valleys which are often bounded by true precipices. The hard rocks stand up precipitously, while the softer strata furnish more gentle slopes. The mountain form, in all of its irregularity and variety, depends upon the action of the agents of denudation upon the rocks of different hardness which have been folded into more or less complex attitudes. Generally the mountains are regions of heavy rainfall; but if they rise to a very considerable elevation, this comes mostly in the form of snow; and even within the tropics,



FIG. 224.

Trail on Long's Peak, Colorado.

the high mountain peaks may be snow-capped throughout the year. Near the base of the mountains, the fact of heavy rainfall causes the growth of luxuriant vegetation, generally in the form of a dense forest covering. As one ascends the mountain sides toward the upper regions of cold, the forest gradually changes in character, at first assuming the habit of the northern forest, then becoming more and more sparse (Fig. 221), and finally, when the timber line is reached, entirely disappearing (Figs. 66 and 223). At the timber

line the forest is replaced by scattered patches of trees; and above this, these forms of vegetation disappear.

As these upper regions of the mountains are approached, the peak becomes more and more rugged. Generally the surface of the ground is strewn with loose boulders, which have been broken from the rock that formed the peak



FIG. 225.

Mountain ridge on the Canadian Pacific.

(Fig. 224). They have been removed from the ledge by the action of frost, and are being disintegrated. Upon these mountain peaks, because of the great cold, frost action is very important. By removing all loose particles, the violent winds check the formation of soil, and the excessive slopes also tend to prevent this; for every drop of water that falls, passes down the steep incline, carrying along all small frag-

ments. The absence of plants removes a protective covering that is important in modifying the action of weathering.

The form and ruggedness of the mountain chain, ridge, or peak will depend upon a variety of circumstances, chief among which are the kind of action which has formed the mountain, the position and structure of the rocks out of which the mountain is made, and the length of time during which denudation has been acting toward the destruction of the mountains. Where there are unusually hard layers in a mountain ridge, these tend to remain high above the surrounding country, and the mountain always has the ridge-like form (Fig. 225); but where the ridge itself has been subjected to variations in folding, in the course of time its ridge-like habit may be destroyed. The massiveness of the rocks forming the mountains also has much to do with their ruggedness. If composed of a series of strata of irregular hardness (Figs. 261 and 262), the topography will be very different from that resulting in a mountain composed of rocks of uniform character (Fig. 251). The most precipitous and rugged of mountains are those made out of rocks of uniform structure. Some of the ridges in the Rockies are made of massive limestone, and among these there are excessively high precipices.

The Origin of Mountains.—Several theories have been proposed to account for the formation of mountain folds; but at the present time no one of these can be said to be thoroughly satisfactory. We are in doubt as to the actual reason for the folding of the surface rocks along certain lines. This much is quite universally agreed upon,—that, in one way or another, it is the result of the heated condition of the interior of the earth. The greater number of geologists also believe that the most satisfactory explanation at present before us, is the one depending upon contraction.

The interior is highly heated, and this heat is passing from the earth into space. As it is lost, the heated interior also necessarily loses bulk, and the cold solid crust attempts to accommodate itself to this constantly decreasing interior. The crust itself does not lose in bulk, and in order to surround the sphere, which is constantly having its diameter shortened, it must wrinkle ; and the comparison is very well made between this supposed action of the crust of the earth, and that which happens when an apple is dried by exposure to the air. As the apple dries, water passes from within, and the interior portion constantly loses in size, while the skin does not lose bulk, but always attempts to surround the apple, and in doing so produces a wrinkled surface.

The mountain and continent folds, and indeed all of the expressions of frequent movement of the earth's crust, are believed by many geologists to be the direct result of this contraction of the interior ; and this theory for the formation of mountains is known as the *contraction theory*. It is possible that there are other causes aiding, and it cannot be denied that there is a possibility of some other explanation. Our knowledge of the interior of the earth is too limited to warrant any dogmatic assertion upon hypothesis.

The growth of mountains is not a stupendous overturning along certain lines, but rather a very slow upward or downward folding of a portion of the rocks. From all the evidence that we possess, there is no reason for believing that any mountain chain in the world has ever grown with suddenness. There is reason for believing that the Coast Ranges of the Pacific slope are even now in the process of growth, and this is certainly true of the Japanese Islands and of the Andes. So far as we may judge, these two latter instances are illustrations of rather rapid mountain growth; and yet, in both places, people find it possible to live with no

other danger than that coming from occasional volcanic eruptions and earthquake shocks. The crust of the earth is not convulsed, but is folded with slowness. This is true even when the rocks break instead of bending. Faults, representing the breaking of the rocks along certain planes, are even now in process of formation in various parts of the world.

If we examine a section of a mountain, we find the rock strata extending from the earth on either side of the ridge (Fig. 226); but their extension into the air has been prevented

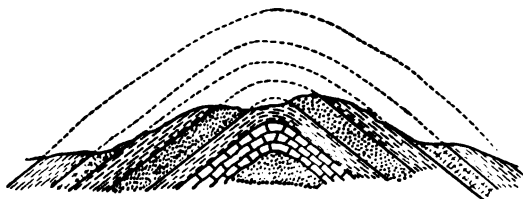


FIG. 226.

Section across a mountain, showing normal extension of strata.

by denudation. The edges of the rock layers have been truncated by this action. If we continue the strata from one

side to the other, joining like layers (Fig. 226), we find that a mountain would result whose height would be greater than anything known upon the surface of the earth. Some of the mountains would be 20,000 or 30,000 feet higher than at present. It is not probable that these mountains ever did extend to this elevation; but rather, that as the rocks folded they were worn away, though not so rapidly as they were unfolded. The folding action was so slow, that the rock layers could be partially reduced and the elevation of the mountains thereby greatly lessened. Therefore, even before the folding of a mountain is finished, a large part of its mass may have been worn away by the agents of denudation (Fig. 229).

Sculpturing of Mountains. — The carving of mountains is

the result of an extremely complex series of actions, and it would be impossible to adequately treat the subject in so small a book. There is always a relation between rock structure and position; and the mountain form is the result of the interaction of the forces of folding and of denudation, which operate differently according to the different positions and kinds of rocks. Some idea of the topography that results from this interaction may be obtained from the accompanying illustrations. (See also Chapter XXI.)

The Drainage of Mountains. — The drainage of mountains is generally guided by the rock structure, or else by the rock position. Valleys are liable to be formed in layers of relatively soft rock, and streams are liable to have their courses guided by the ridges of the mountains. Therefore one of the characteristic features of mountain drainage is that of parallelism between mountain ridge and stream course (Fig. 227). The tributaries to these *longitudinal* streams, flow down the valley sides in direct courses; and occasionally the streams cross the mountain ridges (Fig. 228) through deep and rather narrow gorges. It is possible that in some cases these *transverse* valleys are along the courses occupied by the streams which existed upon the country before the mountains began to form. Such are known as *antecedent* valleys, since they had their direction determined before the mountains began. It is believed that these streams were able to maintain their course across the growing mountains; and if this really be so, it is another evidence of the extreme slowness of mountain

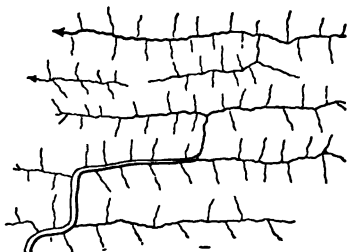


FIG. 227.

A bit of mountain drainage.

growth; for if mountains are folded no more rapidly than streams are able to cut their channels, then their growth must be remarkably moderate. Since there are other possible explanations for these transverse valleys, we must consider this explanation as merely an hypothesis.



SCALE OF MILES
0 1 2 3 4 5 6

FIG. 228.

Mountain drainage.

Lakes are very common among mountains, their origin in these places usually being the folding of the rocks, which form dams across the stream courses. By this action of rock folding, streams may, in some cases, be transformed into lakes which maintain an outflow in the same direction which the river formerly held; or, in some cases, folding of the rocks may actually turn the stream from its course, and make it begin to cut

a valley at one side. Since the origin of these mountain lakes is that of rock folding, it very often happens that they are exceedingly deep. Generally their area is not great; but there are some immense basins, the interior basins previously described, which have all the characteristics of lake basins, but which are prevented from being

occupied by lake water because of the slight rainfall of the region in which they exist.

Destruction of Mountains.—It has been said that mountains are the combined result of the folding of rocks and denudation. When they are growing, the action of folding exceeds that of denudation, and the mountains continue to increase in elevation (Fig. 229). With this increase, stream action and the action of weathering have their power increased, and the mountains are very rugged. They are rugged partly because they are high, and partly because they are deeply carved by stream erosion. Therefore the highest and most rugged mountains in the world are the youngest; and among such mountains, lakes are usually present; for the recent, or perhaps the present folding of the rocks has transformed a part of the streams into lakes.

After the folding has ceased, there is no longer a tendency to become higher; but the action of denudation still progresses uninterruptedly, and this tends to constantly lower the mountains, and, in the course of time, to render them less irregular. The lakes are removed, the mountain

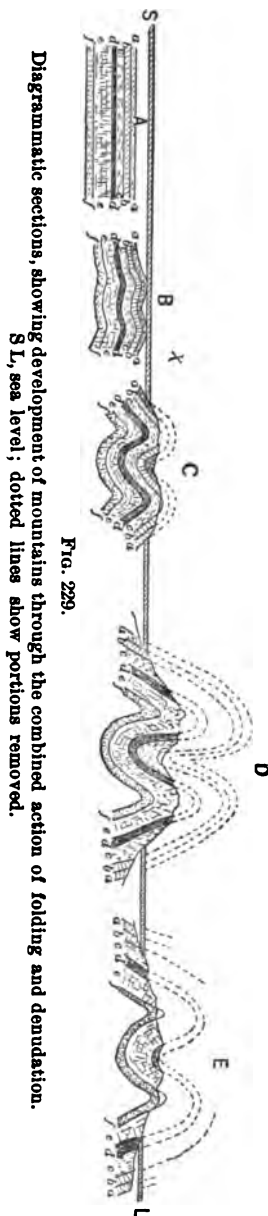


FIG. 229.

Diagrammatic sections, showing development of mountains through the combined action of folding and denudation.

peaks lose in elevation, the ridges are worn down, the streams have chosen the softer layers for their valleys, and the aspect of the mountains has become quite changed. This is the stage which has been reached by the Appalachians. These mountains were once much higher than now; and since they have long been exposed to the destructive action of weathering and erosion, they have lost their ruggedness, and are strik-



FIG. 230.

A mountain ridge in Colorado, showing hard layers etched into relief.

ingly in contrast with such as the Rockies, the Himalayas, and the Alps, which are examples of young mountains.

This action of destruction may be carried beyond the stage reached in the Appalachians, and whole mountain chains may be worn down to their very roots, and reduced to a series of relatively low hills. The highland portions of New England, New Jersey, and the entire region from this state

to the Carolinas, east of the base of the Appalachians, represents such an old mountain range.

As a result of this mountain destruction, many interesting changes are brought about; but the most striking result is the etching of the surface, so that everywhere the elevations are those of hard rocks, while the depressions occur in the soft strata. At first the mountain ridges may have had for their surface rock some soft layer which was bent up into a ridge (Fig. 262). But after long exposure to denudation, the soft layers are worn down most rapidly, and the hard ones allowed to stand up (Fig. 230), so that there is this final result of relation between the rock structure and topography. This change may often go so far as to transform the old mountain valleys to mountain tops, and to wear down the original mountain ridges until they have become mountain valleys. Among the Appalachians there are numerous instances of this transfer of conditions; and we then have represented what are known as *synclinal mountains*, the nature of which will perhaps best be understood by an examination of Fig. 229, E.



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Reade.—THE ORIGIN OF MOUNTAIN RANGES. Taylor & Francis, London, 1886. 8vo. 21s.

FOR STRUCTURE OF APPALACHIAN MOUNTAINS, and an account of experiments in mountain folding, see Willis, Thirteenth Annual Report, U. S. Geological Survey, Washington, 1893.

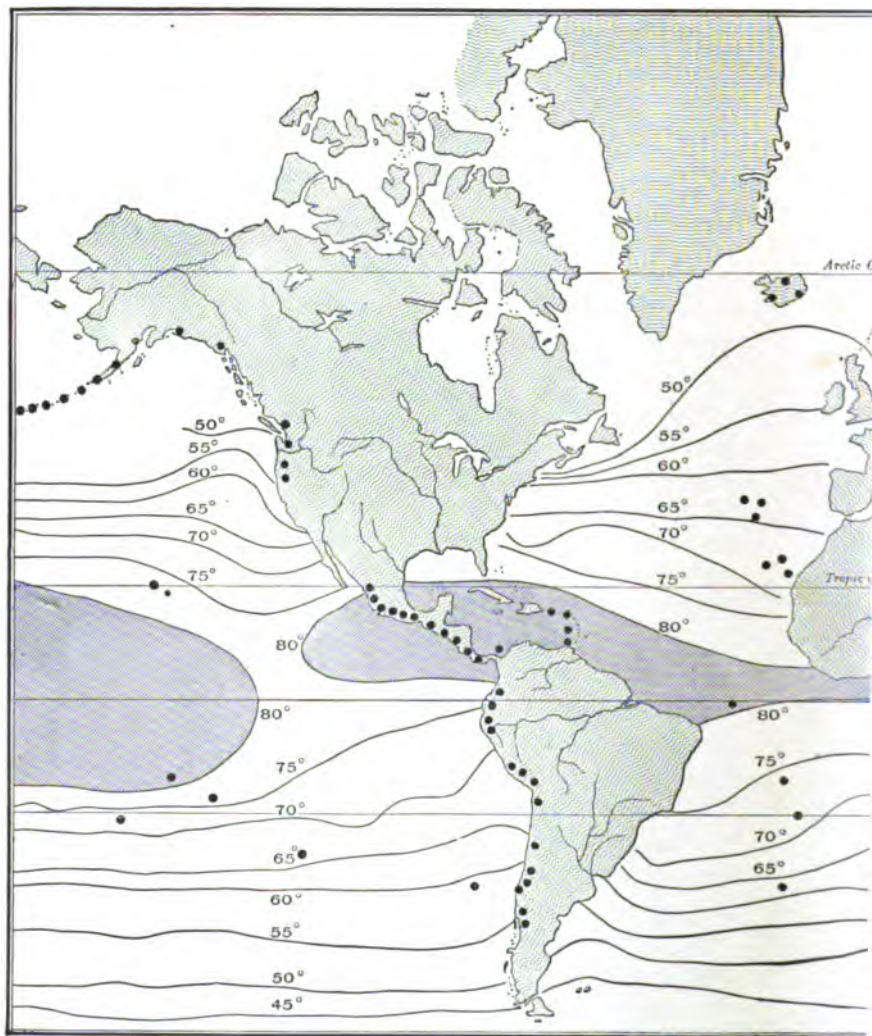
For structure of BASIN RANGES, see Russell, Fourth Annual Report of the same, 1884.

CHAPTER XX.

VOLCANOES, EARTHQUAKES, AND GEYSERS.

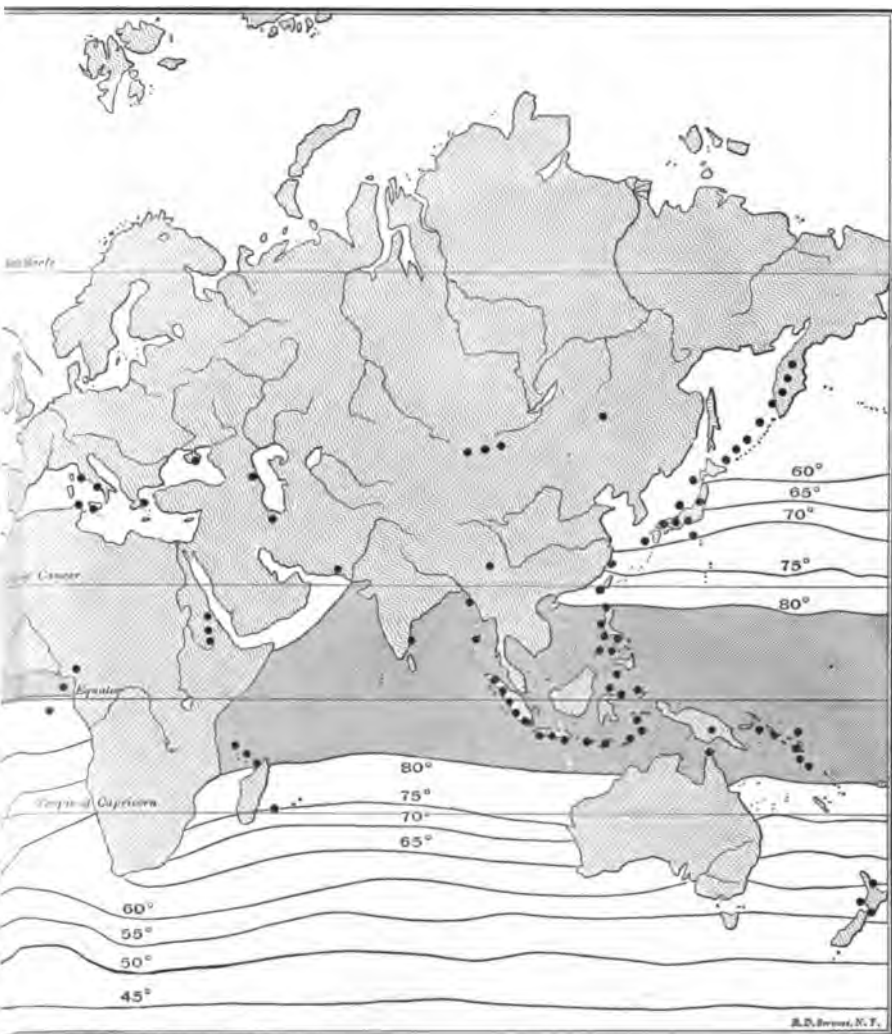
Volcanoes : *Distribution.* — Nearly all of the volcanoes of the earth are located either in the ocean or within a short distance of the coast (Plate 27). They occur in lines, and are very commonly present in the highest mountains, although such systems as the Himalayas and the Alps furnish exceptions to this. The mountains with which they are associated are those in which there is a gradual growth at present in progress. In many cases they occur in archipelagoes near the coasts of continents. There is a line of recent volcanoes, along which there are many still in action, extending from South America to Alaska: then crossing to the Asiatic coast, the line continues down to the East Indies. This is the most extensive volcanic belt of the world.

The greater number of the volcanoes are now found in the Pacific or on the borders of this ocean. Though there are some in the Atlantic, this ocean is comparatively free from them. Along the mid-Atlantic ridge there appears to be a line of volcanic action, and some of the cones are still in eruption. Iceland and Tristan da Cunha are situated on opposite ends of this line, while the Azores, Canaries, and other islands are also in the belt. Volcanoes also occur in other parts of the earth, and there is reason to think that in some places they are present beneath the surface of the ocean. Indeed, volcanic cones have been known to rise above the sea, two instances of this being, one in the Mediterranean and the other off the coast of Alaska.



Face page 370.

PLA:
Approximate distribution of active and recent volcanoes. A



Page 27.

Also the annual isotherms of the waters of the ocean surface.

In the United States, excluding Alaska, there are now no volcanoes which are known to be in eruption. Both in Alaska and in Mexico there are active cones; and in the northwestern part of the country, in the state of Washington, there are some whose form is so perfect that they may still be active volcanoes in a dormant condition. Indeed, there are reports that some volcanoes in the far west have been in eruption since the region was inhabited. While at present there is very little if any volcanic activity in this country, the Cordilleras of the west have just passed from a period of most remarkable volcanic action. There are thousands of cones on the plateaus and in the mountains of this region, some of them perfect in form, as if still in action, others the nearly destroyed remnants of cones.

In other parts of the world there are regions in which there are now no volcanoes, but in which there has been much volcanic action during the past geological ages. This is true of the Auvergne region of central France, of the British Isles, of the east coast of the United States, and many other places. On the other hand, there are areas of the earth in which volcanoes are not only now absent, but from which they have always been absent since the beginning of the Cambrian time. This is true for most of the plains of the Mississippi valley.

Materials Erupted.—Steam is perhaps the most important of substances emitted from volcanic vents (Fig. 231). This is important not merely because it occurs in vast quantities, but also since it is the immediate cause for the volcanic eruption. Of solid materials there are two important classes, the *lava*, which reaches the surface as molten rock and then cools, and the *volcanic ash* or *pumice*, which is really lava blown full of holes and made light and porous. The pumice is made into this form by the expansion of the steam which

was imprisoned within it while the molten rock existed beneath the surface of the earth. Besides these, there are less notable quantities of other substances, chiefly certain gases, such as hydrogen, chlorine, sulphurous gas, etc.

Some of the steam passes into the air as vapor, but much of it falls to the earth near the volcano, producing very heavy rains, and often causing deluges in the neighborhood of the cone. During an eruption there are often violent thunder

storms, in which the rain is largely derived from this source. When the water falls upon a cone whose surface is strewn with volcanic ash, the torrents of water wash this loose material down the hillsides, and a great *mud flow* is produced. These are often very de-



FIG. 231.

Vesuvius in eruption, 1872.

structive, and it was such a flow as this which buried the city of Pompeii during the eruption of 79 A.D. (Fig. 236). The mud flowed over the houses, entered cavities, and formed casts of objects, thus protecting them from destruction, so that in the excavations which have been made during the present century, we have obtained very perfect records of the conditions under which the Romans lived 1800 years ago.

The *lava flow* reaches the surface as a mass of liquid rock, and passes down the side of the cone, often extending

far beyond the base and deluging the country over which it passes. It advances first as molten rock, then a slight crust forms over it, and its motion becomes relatively slow. Toward the last of the eruption, the lava is covered with such a thick crust of rock that one may walk upon its surface, although at the depth of a few feet there is still molten lava. The surface of such flows is extraordinarily rough; for as the liquid part moves, the solid crust is often broken into fragments (Fig. 232). In some rough-surfaced lava flows, it is almost impossible for a person to travel over the lava boulders.

The lava does not extend to a very great distance from the place of ejection, for the flows are rarely more than 20 or 30 miles in length. Therefore the effect of a lava flow is relatively local. In some places, as for instance in the Snake River valley of Idaho, and in other parts of the plateau region of the west, lava has reached the surface through great fissures. Instead of building up a cone it has welled out and spread over the surface, filling valleys, and often submerging hills, over areas of thousands of square miles. In places the lava fills the valleys to the depth of 2000 or 3000 feet.

During an eruption in which *ash* is sent to the surface, these light rock fragments are often ejected to great heights in the air, in some cases apparently reaching elevations of several miles above the surface. The heavier fragments fall back upon the cone, or in its immediate neighborhood; but many of the lighter fragments are sent so high into the air,



FIG. 232.

Surface of a recent lava flow
in the west.

that before they have been able to fall, they are blown by the wind currents to a considerable distance from the cone. In the very violent eruption of Krakatoa, in the Straits of Sunda (in 1883), the finer particles of volcanic ash extended so high into the air that they did not entirely reach the earth for a year or two. It is estimated that the fragments reached a height of 50,000 feet; and this ash in the upper



FIG. 233.

Lake formed by a lava dam, to be seen in the background.

layers of the air, drifted over the earth in the prevailing currents, causing brilliant sunsets in both Europe and America. Since volcanoes are largely located either in or near the sea, much of the ash that is erupted, falls upon the surface of the ocean and drifts about; for pumice is so light that it will float upon water. After the eruption of Krakatoa, vessels

sailing in the region of the East Indies, often encountered so much floating pumice that sailing was difficult. Some of this is stranded upon the coast and broken into small bits of sand, but much of it drops to the bottom of the ocean; for the pumice either decays and breaks into fragments, or else becomes waterlogged and sinks to the bottom.

Eruptions of Volcanoes.—There is a great difference in the kind of eruption in different volcanoes, and even at dif-

ferent times in the same cone. On the Lipari Islands, of the Mediterranean, there is a small volcano which is in almost constant action (Fig. 234). The eruptions are of ash, and the violence is not great, so that sailing vessels may pass by the island without danger. So far as the history of these islands is known, there have been no real destructive eruptions. In



FIG. 234.

the case of Krakatoa, on the other hand, there has been but one eruption during the present century. In the spring of

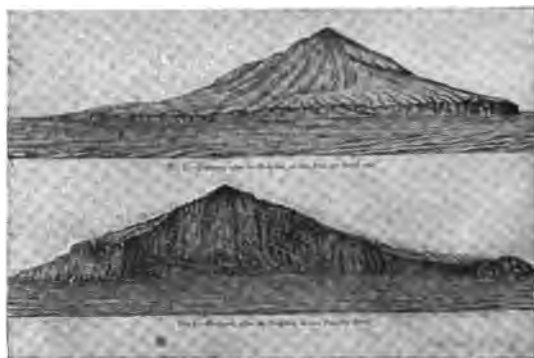


FIG. 235.

Diagram showing the disruption of Krakatoa.

1883 there were signs of activity in the volcano, and these increased until August, when occurred the most remarkable eruption of recent times. One half of the cone was entirely blown away (Fig. 235); and where the high volcanic island existed, there is now deep water in place of a part of the island. There are numerous other instances of violent eruptions, and in

Iceland these are not at all uncommon.

Many volcanoes have violent eruptions at one time, and then moderate action. This was the case with Vesuvius, which was not in eruption from the time of the first occupation of Italy,



FIG. 236.

Vesuvius, from Pompeii. Monte Somma on the right, in the background.

until the year 79 A.D. (Fig. 236). Then an explosion took place which was the most vigorous that has been experienced in the recorded history of the cone. A very considerable part of the old mountain, which was known as Monte Somma, was blown away, and a number of towns were destroyed, including Pompeii and Herculaneum. Since then, Vesuvius has frequently been in eruption, but none have equaled that of 79.

Ash-erupting volcanoes are usually more violent than

those which send forth lava. Of the latter kind, the volcanoes of the Hawaiian Islands furnish excellent illustration. Here one may stand on the margin of the crater and look upon a great lake of molten rock. The surface of this lake gradually rises; and, after several years, a lava flow breaks through the side of the cone and flows down toward the base, while at the same time the surface of the lava lake rapidly descends. The eruption is not from the crater, but through fissures that are broken in the side of the cone. The activity of these volcanoes is never excessive.

The most violent volcanoes are those in which there are the longest periods of rest between eruptions. The tube through which the lava escapes becomes filled with solid rock, and this appears to act in a measure like the closing of the safety valve of an engine. The steam, which is the immediate cause for the eruption, finally accumulates sufficient force to blow out the plug, or else to blow away a part of the cone.

Volcanoes might be divided into three groups upon the basis of their condition. Some are *active*, and their periods of eruption are variable, in some cases being many years, in others only a few years, or even less than a year apart (Figs. 231, 234-236, and 239). A second group is that of the *dormant* volcanoes, in which there is no present sign of activity, but which at any time may break forth in eruption (Fig. 238). Vesuvius was a dormant volcano, and the inhabitants of the region believed it to be free from eruption; for towns and vineyards dotted the slopes of the mountain when it began to break forth in the year 79. After this long period of rest, the length of which cannot be estimated, but which certainly covered several centuries, Vesuvius became an active volcano, and has maintained this condition ever since. After

awhile any volcano will cease action permanently, and then it becomes *extinct* (Fig. 237). The lesson taught by Vesuvius and Krakatoa, should lead us to include in this group only those volcanoes which have been quiet for so long a time that there is almost no possibility of eruption. It is possible that some of the supposed extinct volcanoes of the far west are really dormant (Fig. 238).



FIG. 237.

Mt. Hood — an apparently extinct volcano.

Form of Cone. — When a volcano first begins to form, an opening is made in the ground, through which ash and lava are emitted, together with steam and other gases. The accumulation of the ejected materials soon builds a cone around this orifice. A single eruption will suffice to form a cone, the reason for the conical shape being, that the greatest quantity of material accumulates nearest the place of ejection.

tion (Fig. 234). With successive eruptions the cone grows higher; and if they continue through the same opening, there is produced at the top, and in the center of the cone, a crater which leads down into the interior (Fig. 234).

If weathering and erosion were not present to destroy the conical form, in volcanoes that emit ash we would have produced a very perfect cone, whose angle of slope would be as great as that assumed by gravel when at rest. It is probable that this is approximately the form of the cone which is built beneath the surface of the ocean, where there is no action of denudation. On the land there is constantly a tendency to remove the materials



FIG. 238.

Muir's Butte, California — a volcano recently in eruption.

which are building the cone. Instead of a slope equal to that of a gravel bank, the angle is lessened by the washing action of rain, and the cone is gullied by stream valleys. In some cases, where ash is ejected in great quantities and frequently, the angle of slope is high, and the form of the cone quite perfect. In some of the sharpest cones the angle of slope is as great as 25° or 30° . This is illustrated in Popocatepetl in Mexico, and in Fusi-yama (Fig. 239).

Violent eruptions tend to destroy the perfection of the cone; and in the case of Krakatoa, the volcano was divided into two parts, one of which disappeared into the air (Fig.



FIG. 239.

Fusiyama — a Japanese volcano.

235). The same is true of Vesuvius, and a part of the old rim which formed Monte Somma was blown away; and now Vesuvius, as viewed from Pompeii, shows a perfect cone

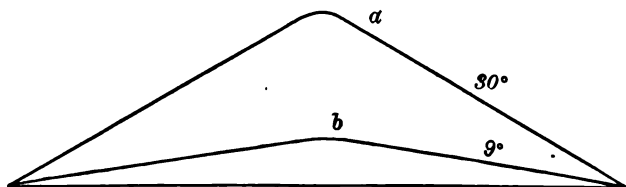


FIG. 240.

Angle of slope of volcanoes. *a*, extremely steep ash cone (approximately represented in Fusiyama and in submarine volcanoes); *b*, lava cone (Hawaiian Islands).

partly surrounded by a mountain wall, which is the remnant of old Somma (Fig. 236).

The eruption of lava produces a very much flatter cone. This is well illustrated in the Hawaiian Islands, where,

although the volcanoes are exceedingly high, the slope is quite moderate, being less than 10° (Fig. 240). This is due to the fact that lava tends to flow away as water does, and consequently to broaden the cone as well as to lessen the slope. Many volcanoes are at one time erupting ash and then lava; and the cone produced is intermediate in form between these two extremes. Such are Vesuvius and *Ætna*, and indeed the majority of the volcanoes in the world.

Effects of Volcanic Eruptions.—One of the most important effects of eruptions is the addition of rock material to the surface from underground sources. An appreciable part of the rocks of the crust have been produced in this way. Volcanic action also furnishes heat to parts of the earth, especially where rocks are injected; and this is one of the causes for hot springs, for many mineral veins, and for the metamorphism of some rocks. The lava flows also interfere with the drainage of streams, sometimes damming them and forming lakes (Fig. 233), at other times occupying valleys and causing the streams to begin the work of formation of new gorges.

When eruptions occur in the ocean, great waves are produced, which sweep upon neighboring coasts, and often cause vast destruction of life. In the East Indies, the low-lying coasts are frequently subjected to this danger (see pp. 178, 179). Earthquakes are also produced as a result of volcanic eruptions; and both by this indirect means, as well as by the lava and ash from the eruption, the destruction of human and animal life is often very great. It is estimated that over 50,000 lives were lost during the eruption of Krakatoa. Practically every vestige of life was extinguished from the island, and the destruction extended to neighboring islands.

Extinct Volcanoes.—When a volcano has ceased action,

the forces of denudation seize upon the cone and wear it away. At first the regularity of the cone is destroyed by the gullying action of streams (Figs. 237 and 241), then its size decreases, and finally merely a remnant of it is left. This remnant is always that of the central part of the cone, partly because this is the divide and hence less exposed to



FIG. 241.

Mt. Shasta on the left; Shastina, a more recent cone, on the right.

erosion, but mainly because it is the place where the hardest rock occurs. The old vent or tube of the volcano is filled with rock from the last eruption that has occurred; and since this is less porous than the lava or ash that forms the cone itself, it is much more resistant to weathering. These *necks* or *plugs* (Fig. 242) of volcanoes are present in all regions

where volcanic action has recently ceased. Upon the western plateau there are thousands in all stages of destruction.

As the volcano disappears, denudation reaches places into which lava has been intruded in the form of dykes or bosses; and when these are harder than the surrounding rock, they stand up as ridges. With the wearing away of the surface, the lava flows also disappear; and where they are harder than the rocks upon which they rest, they often protect these from destruction, causing flat-topped hills and small table-lands. These lava-capped buttes or mesas (Fig. 218) are very common in the regions between the Rocky Mountains and the Pacific coast.



FIG. 242.

Mato Tepee, Wyoming — an old volcanic neck.

Cause of Volcanoes. — The immediate cause of volcanic eruptions is the presence of steam; and in a measure the eruption may be compared to the bursting of a boiler. There is steam present in a superheated condition, this tends to find relief, and the eruption occurs. The origin of the heat which causes the melting of the rock cannot be stated. It has to do with the heated condition of the earth, and since we are not certain just what this condition is, we of course are not able to state what causes the molten rock. The same cause that produces the folding of mountains appears to operate in the formation of volcanoes; and the volcanic action is in most cases, if not in all, an indication that the crust is folding.

Earthquakes. — By far the greater number of earthquakes

occur either near volcanoes or among mountains, though some have occurred at great distances from either of these.

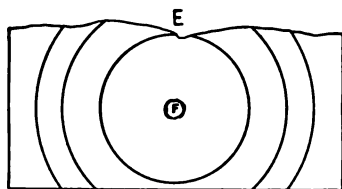


FIG. 243.

The earthquake wave. E, epicentrum. F, focus.

The earthquake is a jarring of the rocks, caused by some shock which is transmitted as a series of spherical waves in all directions through the strata. The point of origin of the shock is known as the *focus* (Fig. 243), and from this center the earth waves move in all

directions. If the rocks were of uniform texture, the earthquake waves would have a spherical form; but since the strata vary in character, the rate of motion differs, and consequently the spherical form is distorted (Fig. 244).

The point on the earth's surface directly above the focus is known as the *epicentrum*, and this is the place where the shock first reaches the surface. The waves come from the earth at equal distances from this point, and on all sides of it. If the rock texture were uniform, the shock would

be felt at the same time at all points whose distance from the



FIG. 244.

Earthquake waves of Charleston earthquake, showing effect of folded rocks of Appalachians.

epicentrum is the same. The most violent part of the earthquake is in the immediate vicinity of the center, while it decreases quite uniformly away from this (Fig. 245).

Even during violent earthquakes, the amount of movement of the rocks is not very great; but the effects of the jar are often very disastrous. Parts of cliffs are thrown down, landslides produced, houses destroyed (Fig. 246), trees overturned, and general destruction caused. The destruction of human life is greatly increased by the fact that houses are readily thrown down by earthquake waves. When earthquake shocks occur in the ocean, great sea waves are often produced, and these, sweeping upon the coasts, devastate the lowlands.

Any jar in the earth will produce an earthquake. During the explosion of dynamite at Hell Gate, near New York, a few years ago, a shock was started which was measured as far away as Washington on the one side, and Boston on the other. The great earthquake shocks are evidently connected either with volcanic eruptions or with faulting in the rocks. The violent eruption of a volcano, like that of Krakatoa, sends a series of earthquake waves through the rocks; and in

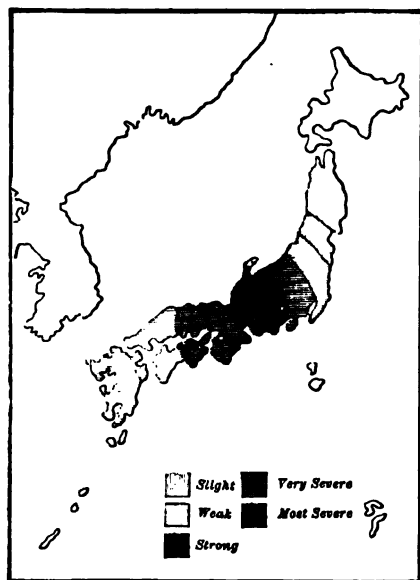


FIG. 245.
Earthquake shock in Japan.

the time immediately preceding these eruptions earthquake shocks are very common, being apparently the result of mechanical efforts of the lava to force its way to the surface. As the cracks are broken apart each step in its progress toward the surface produces a jar. When mountains



FIG. 246.

Effect of earthquake in Japan, 1891.

are being formed, rocks are often broken and faulted; and as they break and slip, waves are started which produce earthquake shocks (Fig. 247). Many of the most violent earthquakes of the world appear to be attributable to this cause.

Geysers and Hot Springs.—Underground water, after a passage through the earth, often finds its way back to the surface in a heated condition. In such cases hot springs are produced, and these are generally mineral springs; for

hot water, in passing through the crust, finds many mineral substances which it can dissolve (Fig. 105). Hot springs are quite commonly found in association with volcanoes; and it is very probable that the heat of the water is in most cases furnished by some supply connected with volcanic ac-



FIG. 247.

Breaking of the earth along the fault line which caused the Japanese earthquake shock of 1891.

tion. Even after volcanoes have ceased activity, hot springs may remain in the neighborhood.

Sometimes hot springs have the peculiar habit of bursting forth into eruptions of steam and hot water, and then a *geyser* is produced (Fig. 249). A geyser may be defined as a hot spring which has a habit of intermittent eruption. One of the geysers of the Yellowstone Park region, the Artemesia, was for a long time known as a hot spring, and then suddenly

the water is so hot that it boils, and the steam which is evolved escapes through the cracks and crevices of the rocks. In some cases the water is so hot that it boils, and the steam which is evolved escapes through the cracks and crevices of the rocks. In some cases the water is so hot that it boils, and the steam which is evolved escapes through the cracks and crevices of the rocks.



FIG. 24.
Geyser erupting in the Nevada Park.

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There is a great difference in the time between the eruptions of geysers, some erupting every few hours, others having long intervals of action. Hot water slowly boils in the tube, then it overflows gently, and suddenly, with very

little warning, bursts forth into eruption, when the air is filled with a great column of hot water and steam, which in the case of the larger geyser usually rises to a height of 100 or 200 feet (Fig. 249).

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FIG. 249.

Old Faithful Geyser, Yellowstone Park.

EARTHQUAKES.

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For a description of the **CHARLESTON EARTHQUAKE** of 1886, see Dutton, Ninth Annual Report, U. S. Geological Survey, Washington, 1889.¹

¹ Nearly all of these articles in the U. S. Geological Survey Reports are well illustrated; and since many of them are readily obtained free of cost, they should be widely used.

CHAPTER XXI.

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General Statement.—Land forms are of two kinds: (1) those that have been *built* by some agency and (2) those that have resulted from the combined action of building and carving. By far the greater number of land forms are of the last origin, and there are few that have resulted exclusively from constructive action. There are two sets of forces working upon the earth in an effort to modify its surface: the one internal, which tends to make the surface diverse, the other mainly external and tending to level. As a result of the action of the former, the earth's surface is thrown into a series of waves, great and small, and some of these are even now in process of formation.

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Utah plateau (Plate 28). The present land form is the result of the complex interaction of these forces, and it is still in process of change.



PLATE 28.

Brink of Marble Cañon, Colorado River.

Some parts of the earth are now being built up, others are being worn down by one cause or another. As a result of this, the surface of the earth presents most complex features ; but if we look at the causes and influences that are at work, it becomes a much more simple task to account for them. These may be briefly summed as follows : The crust of the earth is in *movement*, in some places upward, in others downward, here by broad uplift or down sinking, there by the more local and intense upfolding or downfolding which accompanies mountain growth. Some regions are therefore naturally high, others low ; some are mountains, others plains, and still others plateaus. *Denudation* is everywhere at work ; and since the conditions are variable, the results are quite different. Its action upon plains differs from that upon plateaus ; and in regions of horizontal strata, its effect is quite different from that produced when the rock position or attitude is complex. Not merely does the difference in *rock position* produce a perceptible effect, but the variations in *resistance* to weathering and erosion are of most fundamental importance. These agents of denudation are also engaged in the work of construction ; for the materials taken from one place find rest in another, and often the two processes of tearing down and building up overlap.

Constructive Land Forms : *By Internal Forces.* — It is to be borne in mind that in nearly every part of the land, no matter what the origin of the surface features, there is evidence of the action of the destructive denudation ; and therefore in this section we deal merely with the skeleton, not with the perfected form. The larger diversities of the earth's surface, although greatly sculptured, owe their main features to the action of contraction of the earth's interior.¹

¹ Accepting the contractional hypothesis, as we may fairly do, for a working hypothesis.

Thus the continents and mountains, considered without reference to details, are true constructional forms, being built by the folding of the rocks. In the same way, many of the plateaus, such as those which lie at the base of the Rocky Mountains, are due to the elevation of a part of the earth's crust; and many plains have also been given their present condition by land movements. This is the case with the coastal plain which forms the eastern margin of the country south of New York. This represents an old, nearly level sea bottom, very recently raised into the condition of land; and another elevation of this part of the continent to a height of 600 feet, would add a plain which in some places would be more than 100 miles in width.

The volcano is also a constructional form dependent upon the heated condition of the rocks beneath the crust (Figs. 234-241). It is built up and is formed into a typical topographic feature; but under different circumstances this form varies somewhat. The cone results from the piling up of materials derived from beneath the crust, and accumulated into a conical heap around the place of ejection. Partly because of denudation, and partly because of the explosive action of some eruptions, the cones are much less perfect than they normally tend to be.

By Agents of Denudation. — Some topographic features are produced directly by the building action of the agents of denudation; but these are usually of minor importance. As a cliff crumbles away, talus deposits accumulate at its base, and these often produce great sweeping slopes at the foot of steeply rising mountains (Figs. 118 and 219). Sometimes this curve unites with that caused by denudation, and a double curve is then produced. The wind often blows sand into mounds, and these may cover great areas, completely burying the underlying topography. These are par-

ticularly liable to be formed near seacoasts (Fig. 120); but sand-dune areas are also common in arid regions.

When filled with sediment, and transformed to swamps or plains (Fig. 172), constructional forms of monotonous regularity are often built in the site of lakes. The same condition results when lakes are displaced by other causes, as is the case when they evaporate; and many of the great *alkaline plains* or *flats* of the Great Basin are old lake bottoms (Fig. 150). The disappearance of a glacial lake often leaves an extensive plain, as is so well illustrated in the great wheat plains of the valley of the Red River of the North (Fig. 215). In these cases the shore lines are also left, and these topographic forms, though of minor importance, are often striking features in the landscape (Fig. 170). Deltas (Fig. 154), bars (Fig. 213), and spits (Fig. 196) are built up in the lake waters; and upon the disappearance of the lake these are left upon the valley sides (Fig. 170).

Rivers also build deposits, the most notable being deltas and floodplains; but in some cases, terraced valley sides result from the constructive action of the river floods. One of the most important causes for the details of the topography in northern United States, is found in the recent glaciation; and much of this topographic variety is due to the building action of the ice. With the debris that it carried, the glacier formed great plains, either by direct deposition from the ice, or in a secondary way through the intervention of water produced by ice melting. Much of the prairie country of the Central States owes its present levelness to these causes. In other places, hills of peculiar and irregular form were built by the ice. To the majority of people who live in the glaciated belt, these hills of gravel and unstratified till must be familiar features; and in the morainal regions they are strikingly developed. (See Chapter XVII.)

The ocean is the great receiving ground for the waste of the land ; and for the most part the debris is spread quite evenly over the bottom, producing a plain, which in some cases is partly raised above the sea. But along the shore line, the constructive action of the ocean is producing many irregularities, though here, as elsewhere, the actions of tearing down and building up are so intimately associated that it is often difficult to draw the line between them. Still, the beaches (Figs. 200 and 201), the bars, the long sandy islands (Fig. 194), and other similar coastal features, are often mainly the result of the action of the waves and currents in building up materials furnished by various means. When, for any reason, the level of the sea is changed in its relation to the land, these shore-line formations are either submerged, or, if the land rises, are left as ancient shore lines, which then resemble those remaining when lakes disappear.

By Animal and Plant Life.—In various ways, both animals and plants are engaged in constructing land forms. The salt marsh of the seashore (Fig. 206), and the swamps of the land, in part represent this action ; but the most notable action of life in this respect is that of the corals, which are building reefs (Fig. 207). It is true that the corals do not build the reefs above the sea level ; but a slight elevation of the bottom has often raised them to the air. Also, the action of the waves may pile the coral fragments above the reach of ordinary waters ; and wind action, by blowing the coral fragments into dune-like hills, then causes them to rise still higher. By these constructive processes combined, many islands are built in the sea (Figs. 208 and 209).

Effect of Rock Structure upon Topography.—The land forms constructed in the ways above described, are subjected to attacks from all the agents of denudation ; and as a result

of this, the land surface presents many diversities. Under uniform conditions, denudation affects rocks differently according to (1) their elevation, (2) their position, and (3) their structural features. Moreover, the intensity of denudation varies; and as a result of these facts, land forms differ from place to place. It is impossible here to enter into this subject in any considerable detail; but some of the main principles may be briefly stated.

Much depends upon the ease with which materials may be



FIG. 250.

View in Brazil, showing hard layer etched into relief by the removal of the less resistant enclosing rocks.

removed (Fig. 250). In high mountains, where the grade is steep and denudation intense, the etching of the rocks is very sharply done (Figs. 224, 225, 230, and 261); and hence, in such places, we have the characteristic ruggedness of high mountains; but when the mountains are low, even though the difference in rock hardness may be great, the outlines are less angular and more rounded and flowing. In this connection one may contrast the Alps (Figs. 143, 144, and 220) with the Highlands of Scotland, or the Rockies of



PLATE 29.

Navajo Church, Arizona, showing sharpness of denudation in an arid region.
Soft clay, capped by harder rock, in foreground.

Colorado (Figs. 221 and 223) with the Appalachians or the Adirondacks (Figs. 263 and 264).

With conditions of aridity, the soil covering is readily removed from the rocks, so that they are exposed to the air; and hence, here also, angularity and ruggedness of topography prevail (Figs. 122 and 142 and Plates 28 and 29). Oftentimes the streams cannot carry the material furnished to

them, and instead of trenching the highlands, they flow on the surface of a plateau. This is the case with the river Platte. The *intensity* of denudation is therefore of great importance, and this varies with the *stage of development*, so that there is an intimate relation between topography and the *age* of topographic forms.



FIG. 251.

A cliff in the Yosemite.

The young valley is a sharply defined feature (Fig. 133), while the mature valley, in which the intensity of erosion has ceased, is rounded under the more widespread, but more moderate action of weathering (Fig. 135). Altitude is an important element in this connection, but it is by no means the only one.

Much depends upon the rock structure. Even though it be soft, a rock of uniform texture produces massive effects. The granite of the Yosemite (Figs. 164 and 251) is composed of materials uniformly arranged,—hence the bold, regular outlines. Massive beds of limestone produce the same effect; and among some of the ranges of the Rocky Mountains, where the rock is a thick bed of limestone of quite uniform texture, there are places of great precipitous-



FIG. 252.

Cliffs in the loess clay of China.

ness. Even when the surface is covered with consolidated clay, this uniformity impresses itself upon the topography, as is so well illustrated in the Chinese region (Fig. 252). Upon the seashore these massive rocks are often cut into cliffs, which frequently rise to great heights, as in the case of the chalk cliffs of England.

On the other hand, if the rock is in layers, or if for any other reason it is rendered mechanically weak in places, the boldness disappears. On the seacoast, the weakness of the

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slope (Fig. 258). If going in the direction of the dip, one ascends a steeply sloping hill, then passes over a bench to

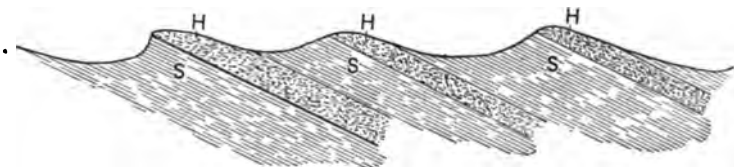


FIG. 258.

Step topography in region of inclined strata. H, H, H, hard layers; S, S, S, soft.

another sloping hill, and this may be repeated many times. If the journey is in the opposite direction, there are a series of descents with intermediate terraces. Looking in the direction of the dip, one sees a series of hills, while the view in the opposite

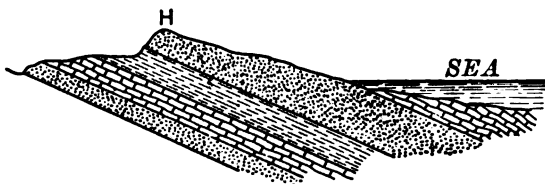


FIG. 259.

H, hard stratum.

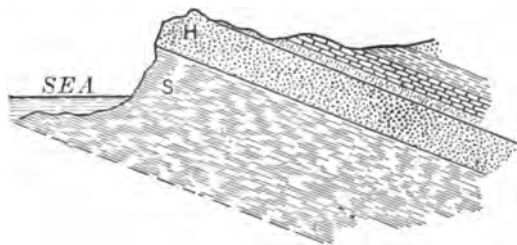


FIG. 260.

H, hard stratum; S, soft.

direction is over the surface of the plain. The flat areas are determined by hard layers, and the steep slopes are also due to their presence; for they serve

to protect the softer underlying layers from destruction.

Where such a series of rocks occurs on the seacoast, the

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tain topography are the result of this etching of folded rocks which present differences in hardness. This is seen among the Appalachians (Fig. 262), where nearly all of the ridges are made of hard strata, and where they form ridges because they are more resistant than the surrounding rocks.

Not merely are there *ridges* where hard layers exist, but *peaks* (Fig. 220) are often produced where unusually hard rocks are found; and very often, where the *general* rock structure is harder than that of the surrounding regions, these places stand up as more elevated areas. Thus the Adirondacks, the New England area, etc., are high mainly because their rocks are

prevailingly hard. When, by land movements, these carved areas are brought beneath the sea, their irregularities impress themselves upon the coast line, as for instance on the coast of Maine, which is a land area

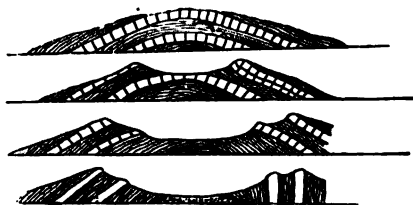


FIG. 262.

Effect of hard layers (unshaded) in the denudation of mountains.

partly drowned by the sea (Fig. 211). The hard rocks which formed hills, now exist as promontories, capes, or islands, while the sites of the softer layers are occupied by bays or straits.

From this brief statement, it is seen that the causes for topographic irregularities are most complex. They are to be found in a combination of internal and external forces. The land is in movement, and the forces of denudation are at work carving and removing, and often locally building. With variations in altitude, position, and kind of rock, many complex results may be produced. Above all, it must be borne in mind that these changes are now in

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CHAPTER XXII.

MAN AND NATURE.

General Statement.—The relation between man and the physical conditions of the earth's surface is most intimate, although in his present civilized state they are very much less important than in the past. Formerly, even slight barriers were almost impassable, while now we cross them with ease. Less than a half-century ago, the journey from the Mississippi to the west coast was of the most dangerous kind, while now, in a few days, we pass over the mountains and plateaus with ease and comfort. While, with the advance of civilization, man is becoming less dependent upon nature, at the same time he is increasing his power to control and modify the surrounding conditions. So the subject of the relation between man and nature naturally divides itself into two parts, (1) the influence of nature upon man, which is of decreasing importance, and (2) the influence of man upon nature, which is all the time increasing. These subjects can be treated only very briefly.

Modifying Influence of Man.—In many small ways man is engaged in the work of modifying the natural conditions of his surroundings. He protects himself from the rigorous climates, and thus makes his existence possible in zones where otherwise he could not dwell. He modifies the forces of nature so that they become his servants. The winds, the rivers, and even the tides are converted into forces which serve him. He confines the river within its banks and pre-

vents the flood; and he turns the river waters from their course to lead them where he wills. Deserts are transformed to fertile gardens; swamps are made dry; the sea is excluded from the marshy lands of the coast lines;¹ and almost everywhere we find evidence that man is at work in modifying the surface. The earth is pierced with mining shafts and tunnels; new water connections are made by canals across the narrow isthmuses; inland towns are connected with the sea; and seashore towns are made into seaports by the construction of artificial harbors.

Notwithstanding the importance of these effects, there is no influence of man more potent than that which he exerts upon the life of animals and plants. Many species are being perpetuated under domestication, and much is being done toward their modification. New fruits are constantly being produced, and in this respect the influence of man is very important. Man is doing a great work in distributing animals and plants over regions which are not properly their homes. Sometimes the effect is beneficial, but very often it is most disastrous. For instance, the rabbit introduced into Australia has become a national pest; and the English sparrow is completely overrunning this country. Insect pests and diseases are also spread, and these attack not merely man, but also the plants and animals.

However, it is in the destruction of life that the most baneful influence of man is noticed. Animals of nearly all kinds, particularly some of the largest, are disappearing before his advance. Several species have been entirely exterminated, and some, such as the bison, which was formerly so abundant, have been so reduced in numbers that they are almost exterminated. By the destruction of birds, the number of insects has been increased; and so both directly and

¹ It is estimated that one-tenth of Holland is land reclaimed from the sea.

indirectly the influence of man in this direction has been harmful.

Man and the Forest. — Probably the most important single influence of man comes from his habit of destroying the forest (Fig. 263). In many ways the forest covering is important. It protects the soil from being washed away,



FIG. 263.

A part of the Adirondack forest. (Copyrighted, 1888, by S. R. Stoddard, Glens Falls, N.Y.)

and when it is removed, and the soil turned by the plow, both weathering and the removal of the loose materials are increased. In some places, notably in France, the mountain sides, from which the forests have been stripped, have been transformed to barren wastes of rock because of the removal of the soil by the rain. In other places, the soil has

been so gullied that it is unfit for cultivation. A part of Mississippi has been transformed to a barren waste of clay, the features of which resemble those of the Bad Lands of South Dakota (Plate 21). The effect of the absence of forests is well illustrated in the arid lands, where the forest covering is absent because of natural climatic conditions. Here every rain gullies the land; and on the steeply sloping hillsides, the removal of the soil by rain and wind action has exposed the bare rock (Figs. 90 and 121).



FIG. 264.
Deforesting in the Adirondacks.

The forest serves to prevent excessive river floods; for it protects the snows from rapid melting, and prevents the rain from readily passing away in the streams. The mat of leaves and moss, the *forest litter*, serves as a great sponge which holds the water. This is important in many ways: for it makes the stream less liable to violent floods; it furnishes a constant and rather steady supply, both to springs and streams; and it furnishes moisture to the air. With the removal of the forest covering, the rain and the melting snow

pass rapidly into the rivers, and thence to the sea (Fig. 264). At times, exceptional floods are produced; and then, when these have passed away, the river rapidly loses in size, until it may perhaps become nearly, if not quite dry (Fig. 124). The greater part of the water passes through the river in a few days. Every person of maturity who has dwelt by the side of a stream heading in a region once forested, but now bared of its tree covering, will bear testimony to the fact



FIG. 255.

Bare rock exposed to weathering by removal of the forest, Mt. Desert, Me.

that streams which were formerly moderate, clear, and permanent, are now transformed to trickling streams, which at times become raging torrents, clouded with sediment.

This influence of man is very disastrous. It not merely causes the removal of soil from the mountains (Fig. 265), but distributes this over the lowlands; and in some places, farms have been rendered uninhabitable by the deposit of sediment during times of flood. Besides this, the floods themselves are very destructive both to life and property;

and, with the removal of the forest covering, they are becoming ever more destructive. Mills cannot count upon the same steady water supply that they formerly had; springs quickly become dry; and there is some reason for believing that the removal of the forest also affects the climate. This latter point has been suspected; but it has never been proven that the forest makes the rainfall more uniform or greater in quantity. The reasons for suspecting this forest influence are (1), that the damp winds, when coming in contact with the cool forests, are made to give up their moisture more readily than elsewhere; and (2) that by holding the water in the litter beneath the trees, a greater opportunity for evaporation is furnished than when the forest is removed. It is held that, as a result of this, the air is rendered moist and is more liable to give up its moisture.

These influences are so important, that one of the needs of the present, is greater care, intelligence, and patriotism in the relation of man to the forest. The conditions need to be carefully studied, destruction ought to be checked so far as possible, and the damage of past destruction should be repaired in every possible case. The state and national governments are in some cases engaged in this work; but it is possible for nearly every one to do something toward it. Unless something is done, the heritage of the land which we have received, will not be transmitted to our descendants in so good a condition as it is our duty to leave it.

Influence of Nature upon Man. — It is quite impossible at present to estimate the effect of nature upon man; for in most respects we have risen above its immediate and most important modifying influences. Without serious difficulty, we cross mountains and continents, rivers, lakes, and even oceans; and in a few weeks we may pass around the entire world. Every generation sees an increase in the independ-

ence between man and nature, and the completeness of the conquest of the latter.

This has not always been so, and many of man's most marked characteristics have had their origin in, or have been impressed upon him by his environment. Even now we find a marked difference between the miner, the ranchman, and the farmer; and, except in the most general way, the effect of climate upon man's condition cannot even be estimated. Both extremes of heat and cold introduce habits of mind and body quite the reverse from the lively mental and physical activity of the inhabitants of the temperate zone. The inhabitant of the Arctic loses vitality because of the unequal struggle; and where no severe struggle for existence is necessary, the enervating influence of the tropical sun also decreases vitality. Under the bracing air of the temperate latitudes, and with the necessity for preparation for the winter, man's physical and mental powers have been improved; and this is probably the most potent reason for the very striking fact, that the most important development of the race has taken place in these regions; and why to-day, nearly every nation of marked importance is situated within the temperate belt, and mostly near the arctic limit of it.

If we glance back to the time when man was less independent of nature, when his railway trains were not present to transport him across river and mountain, nor his steamships ready to bear him across oceans, we find a very close relation between the life of men and nations and the surrounding physical conditions. When a people migrated to a new land, they often found conditions favorable to a rapid development; and if they were sufficiently enclosed and isolated for protection from invasion, they often developed to a high state. However, in time the very isolation caused degeneration; and we see this illustrated in the history of

such people as the Chinese and the Egyptians. Because of the climatic conditions under which they lived, some of the early people became nomadic, others developed into agricultural nations, and still others into seafaring races.

With the growth of commerce, the most rapid progress occurred in the nations most favorably situated for its development. Thus Italy, nearly isolated from other countries, became an important center of commerce. Fresh blood and new ideas were constantly introduced, and gradually the power of the nation increased and extended, until decay came mainly as a result of the rapid development, and the nation crumbled because of its very success. In ancient Greece we find another instance of the influence of surrounding conditions. The very rugged topography favored independence: for even in small areas, different states could exist independently; but because of their very smallness, they were compelled to unite against common foes.

The Mediterranean was the seat of early development; and this was made possible by reason of the short distances between countries, the possibility of navigation in the enclosed sea, and the interchange of materials and ideas. Here the people learned lessons in navigation which made the exploration of the Atlantic less hazardous; and then, by land and by sea, the peoples from the shores of the Mediterranean taught lessons to the more northern races, which, when well learned, made their ultimate success possible; and then the students themselves became leaders. The shores of the Mediterranean were the great training schools, in which were learned most of the fundamental ideas upon which the progress of the human race has depended; and even now its influence is felt most markedly in all the nations of the world.

Perhaps there are no better illustrations of the influence of surroundings upon the development of nations, than those

furnished by Scandinavia and England. The roving Northmen, born on a rocky coast, which was deeply indented with fjords, made the sea a second home. Instead of farming, they fished; instead of remaining to develop their inhospitable coast, they roved the seas and invaded their neighbors. With that hardiness born of the sea, they roamed not only along the European shore, but sought and discovered new lands in the west. They not only learned much themselves, but taught much to others; and the lessons that they learned and imparted were mainly due to their neighborhood to the sea.

In England, we find a most remarkable illustration of the influence of environment. The climate gave vigor to the people; and the mixture of races, that had come in earlier days, made a nation of men with great mental and physical power. The mineral wealth did much to make the subsequent development possible, for it became sought after by many nations. Because of the insular condition, this store of wealth was protected without great difficulty; and yet the islands were readily visited for purposes of friendly commerce, and the stores of wealth were distributed over the world to the profit of the people of the islands. A commerce was readily developed; and largely upon the basis of this, England became what she is to-day, — the great naval power of the world, and the possessor of colonies in every part of the earth. It never can be told how important an event it was in the development of nations, when, in some prehistoric time, the sea first passed through the English Channel, and separated the British Isles from the mainland. With land connection, the history of Europe and the world might have been quite different.

When we look at the maps of Europe and America, two differences of a most striking nature attract our attention.

The one is the extreme irregularity of the European coast line, the other the great number of nations in that land. The latter fact depends upon several causes. The very irregularity of the coast, and the great diversity of the topography, have made possible the development of distinct nations. As the race was progressing, mountain barriers, and even rivers, served as boundary lines between separate tribes; and some of these are preserved to this day. We find Switzerland completely enclosed between other nations, because no ancient tribes could drive these people from their mountain fortress. To fully appreciate the importance of these influences, one needs but examine a physical map of Europe, and notice how the mountains and the seas almost universally serve as boundaries, and how upon every peninsula, there is one, or more, independent nation. This is not so in America, partly because the conditions are not so diverse, but chiefly because the settlement of America was made by races which had already developed.

With the development of knowledge and power, there came an era of exploration, in the course of which America was discovered. Even this discovery depended upon peculiar physical conditions; for had Columbus undertaken to make his voyage either to the north or south of the trade-wind belt, the chances are that he would never have succeeded. With the favorable trades furnishing fair winds, the journey was a relatively easy one.

The explorers and settlers found the American land occupied by nomadic races, whose power of resistance to invasion was not equal to the skill of the invaders; and with the discovery of America there began a new era. Navigation increased; and Spain, who had learned her lesson from Italy, and who was important in maritime affairs because of her extensive coast line, became a powerful nation. As in Italy,

success caused almost utter collapse, and Spain lost more than she gained.

In America, the invigorating climate, the necessity of work, and the great possibilities, developed a race which has become renowned for its vigor and energy. At first the Appalachian barrier, with its almost impassable forests, prevented entrance to the central regions. Therefore, of necessity, settlements were made close by the coast; and it is said that in 1700, one could go by stage from Portland, Maine, to Virginia, spending every night in a good-sized village, while to the west there was an impassable wilderness traversable only on foot, along the Indian trails. The large waterways leading into the interior were guarded, the Mississippi and the St. Lawrence by other nations, and the Mohawk by a powerful Indian population.

This forest barrier caused a concentration of population, upon which much of the success of our later development has depended. It determined the location of most of the great centers of population; and it protected the English until their strength had sufficiently increased to admit of pushing into the western region, and displacing the unfortunate savage occupants. The success of the Revolution also in great measure depended upon the concentration of population thus induced. Had the people been less connected, they could not have coöperated so well as they did.

When, finally, a definite roadway was established across the Appalachians, which was first done over Cumberland Gap in Tennessee, the most difficult step in the western progress was taken. The great treeless prairies were then reached, and upon these agriculture was easily pursued, while further progress was not difficult; and hence the Mississippi valley became speedily developed. When once the way was found, other openings were soon made across the forest barrier.

Then came the discovery of the wonderful mineral wealth of the west; and the eagerness to obtain some of these stores from the bosom of the earth, caused an almost magical development of this great realm. Cities sprang up among the mountains, farms were developed on the desert, railroads crossed the mountain chains, states grew out of hitherto unsettled territories; and, in a quarter of a century, a great region was transformed from an unknown waste, inhabited only by savages, to the most remarkable mineral-producing region of the world. Such progress as this could be made only after man had so far developed as to be able to defy and overcome the most formidable of obstacles.

In this country, the influence of topography upon man is seen in many small ways. In New England, particularly in central Massachusetts, the old interior towns were on the hills, which were fortresses where the people were, in a measure, safe from Indian attack; and even now we find many of these hilltop villages, which at present are scarcely more than relics of a past stage in development. With the development of the industries, manufacturing determined the position of the more important interior towns; and these were naturally placed in the valleys which afforded a good supply of water power.

Hilly New England became a manufacturing region; the states of the level and fertile prairie formed an agricultural district; the drier plains and plateaus of the west became the seat of the cattle industry; and the mountainous region of the far west developed into a mining territory. Many of the larger cities were situated on the seacoast, because here communication and commerce with other countries were possible. Even the sites of these large cities were determined by the form of the coast line; and everywhere that we may go in the world, we find an almost universal relation between

man's condition and his surroundings. The delta lands are farming districts, the semi-arid plains and plateaus are devoted to cattle raising, etc.; but while man is largely a creature of his environment, he is much less so now than ever before; and, little by little, he is rising above the necessity of direct dependence upon the surrounding physical conditions. Formerly he was guided by nature, but now, in many respects, he governs and guides nature to suit his needs.



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CHAPTER XXIII.

ECONOMIC PRODUCTS OF THE EARTH.

Soil. — The crust of the earth furnishes to man most of the material which he needs for life and comfort. The rocks crumble to form soil, and upon this exist the plants which furnish us directly or indirectly with most of our food supply. In this the trees grow, and all of the animals of the land depend upon the plant life which exists by virtue of this soil covering. This is by far the most important mineral product of the earth, for upon it depends our existence as inhabitants of the land.

Building Stones. — Within the earth, as a part of the crust, there are many substances which man finds it possible and profitable to remove for his own use. For instance, there are the building stones, of which we have many kinds. The great masses of molten rock, which have been intruded into the earth's crust from below, and then cooled, and finally reached by denudation, furnish us with great quantities of *granite*, which is such excellent building stone, both with regard to durability and appearance. Sometimes other forms of igneous rocks are employed for building purposes; and among these we find great variety both in color and texture.

Granite is imitated among the metamorphic rocks, where as a result of the process of alteration, a structure closely resembling that of granite is sometimes introduced into the gneissic layers. Indeed, many *gneisses* are sold as granites,

and their resemblance is often so close that one can tell the difference only by a slight banding which characterizes gneisses, but is not usually present in granites.

There are other metamorphic building stones, chiefly slate and marble. *Slate* represents a clay rock formed as a deposit in water, and then subjected to heat and pressure, so that its peculiar cleavage is introduced. *Marble* is the metamorphosed product of limestone, in which the carbonate of lime has in some cases been transformed to crystals of calcite, causing the white sugary marble, such as that found in Vermont. In other cases no crystals are produced, but a remarkable and often very beautiful banding is introduced. The causes for this metamorphism are usually a combination of heat, pressure, and motion during the folding of the rocks.

The sedimentary rocks themselves also furnish us with much building stone, chiefly in the form of *sandstone* and *limestone*. Among these there is great variety, both as regards texture and color; and this class of building stone is extremely common. Indeed, these rocks are so abundant that only the best can be extensively used; and in many places a stone is quarried for home use, but is never transported far beyond the quarry. Few stones, and these mainly ornamental, will pay for transportation to great distances, for there is an abundance of stone for ordinary purposes, and nearly every place has its quarry.

From the *unconsolidated clays* and *sands*, we obtain much material for building purposes. The sand for plaster, the clay materials for some cements, and the clay for bricks, are among the most important of building materials, and their sources are varied. Some are decayed rocks, others ocean deposits, others have been formed by rivers or lakes, and many, particularly in northern United States, have been brought to their present position by glacial action.

Economic Deposits of Sedimentary Origin. — Aside from the sedimentary building stones, and some of the ores, the crust of the earth contains numerous valuable deposits formed in water. Some of the sandy rocks are sufficiently rough to be used for grinding purposes; and the tiny shells of silica, which are left in fresh-water swamps and ponds by certain low forms of animals and plants (Infusoria and Diatoms), furnish a white polishing powder.

When lakes have their outlets cut off, and evaporation exceeds the supply of water, they gradually become salt; and finally they may become so concentrated that some is deposited in the bottom of the lake, and then there is formed a layer of *rock salt*. These layers may be buried beneath other strata, and at some later time be discovered as a salt mine. In the Great Basin there are many beds of this kind, now exposed at the surface, where in some recent times a salt lake has completely dried up; and the ranchmen visit these beds with wagons, and shovel up from the surface all the salt that they need.

At times there are other materials deposited with this precipitated salt. In this way such substances as bromides, borax, natural soda, and even gypsum, which is used as a basis for plaster of paris, are deposited in layers.

Left to itself, the soil furnishes the plants as much food as they require; but when man interferes and tries to draw more than this from the soil, in the course of time he exhausts much of the supply of plant food, and it is then necessary either to abandon the land until it can recover, or else to artificially supply the needed substances. For this reason *fertilizers* of one kind or another are added. Sometimes the fertilizer is only a limestone, or it may be a marly clay in which there are many fossil shells, or it may be one of the natural phosphates. Phosphatic materials are

among the substances needed by plants, and phosphate is present in the bones of many mammals. In some places, as for instance in South Carolina, near Charleston, and in many parts of Florida, there are beds of a phosphatic rock which owes its peculiar character to the presence of large numbers of bone fragments. These are great mammalian burial grounds, and man is now drawing upon them with profit.

Miscellaneous Substances.— There are many other products of the earth, which though valuable, are of minor importance. Springs containing mineral matter in solution often have medicinal properties, and this ensures a wide sale for these *mineral waters*. Artesian wells (page 229) are of no little importance. Sulphur is often found near volcanoes ; graphite, which occurs in metamorphic rocks, furnishes the black lead for our pencils ; mica, asbestos, etc., are also found in the metamorphic rocks ; valuable mineral paints are usually colored earths due to rock decay ; and to these many other minor products might be added.

Coal.— Seams or beds of coal are often found between layers of sandstone and limestone. These enclosing rocks bear evidence of having been formed in water, and the fossils which they contain often prove that they were deposited in salt water. Yet the coal is composed of the remains of land plants, and even tree trunks are sometimes found preserved in the beds. In some cases these fossil tree trunks stand upright, with their roots in the clay beneath, showing that the coal bed is near the place where the plants grew. It is further evident that they were then covered by the sea, and that in this the marine sediment was deposited. Often there are several beds one above another, each proving some such change as this.

Much about the origin of coal cannot be considered to be finally settled ; and there are many theories for its origin.

Since we cannot enter into a discussion of these, it will be necessary to confine ourselves to a statement of what seems to the author to be the most probable explanation. Without doubt, different coal beds have had a very different history. Some represent the drifted fragments of wood that have been deposited in an ancient bay or estuary, and then buried beneath marine deposits. Thus if the Mississippi delta should be consolidated into rock and be elevated, there would be coal seams formed where rafts of logs have been stranded.

There also seems to be no doubt that some coal beds are nothing more than swamps which were formed either on shores of lakes, or as the last stage in their disappearance, — in a measure being like peat bogs consolidated to mineral fuel. In the southern part of Florida there are a great number of swamps, and swampy lakes, in which there is a vegetable accumulation several feet in depth. This muck is made almost entirely of plant remains with practically no clay impurities. If this low, swampy land were to be lowered beneath the sea, these beds of vegetable matter would be covered with sediment, and a coal bed would be begun. Later the same conditions might be repeated and another bed be formed, etc.

Even at present, some trees (the mangrove, Fig. 205) grow in salt water; and in the early geological ages many others probably had this habit, for the land vegetation of these early times was evolved from marine plants. At this time there were probably great salt-water swamps, in which many of the coal beds were formed. Very likely each of these theories accounts for some of the beds.

The coal is a mineralized form of vegetation, produced by a slow change, in the course of which many of the volatile gases have been driven off. There is every gradation from

wood to peat, from this to lignite or brown coal, then to bituminous, next to anthracite, and finally even to graphite. This does not require great heat, but slow, steady change. The ash of the coal is an impurity, often bits of clay and sand that were deposited with the coal.

It was once supposed that coal was formed only at one period in the history of the earth, and this was given the name Carboniferous; but with the exploration of the Cordilleras, this has been shown to be a wrong idea. Workable beds of coal were not formed *before* the Carboniferous time, because in those early ages there was not enough land vegetation; but ever since this time, coal has been formed wherever the conditions have been favorable. In the west there are vast quantities of Cretaceous and Tertiary coal. Indeed, in such places as the swamps of Florida, the Dismal Swamp, and the peat bogs of the north, it is quite probable that we are even now witnessing the first stages in coal accumulation.

Natural Gas and Petroleum. — In some places, wells drilled into the sedimentary rocks reach layers containing either a natural illuminating gas, or petroleum. These products are very useful, the gas for fuel and light near the wells, the oil for the basis of kerosene, and numerous other products. These substances occur rather irregularly; and wells upon neighboring farms may in the one case find oil, while this is not discovered in the neighboring well. However, certain layers are liable to be oil bearing, while others are never known to contain oil or gas. After awhile both the oil and gas wells gradually decrease in volume, and must finally be abandoned. Therefore the supply is not constantly furnished at as rapid a rate as the drain.

These substances are the product of a slow natural distillation of the organic remains of the rocks; and they quite

closely resemble substances which we produce artificially. The oil is not markedly different from that produced from fish refuse; and the gas resembles the illuminating gas caused by distilling coal. The change is a slow one, and in the course of time, enough accumulates in a certain layer to make a gas or oil deposit. In some cases this accumulation is in the same layer in which the distillation took place; in others, the substances have migrated into a neighboring layer. Like water, they are able to slowly seep through the rocks; and in their passage, they may come into a coarse sandy rock, and be imprisoned there by an overlying clay layer which is too impervious for easy passage. In these cases there is a resemblance to the conditions favoring artesian wells. This is the common case in the Pennsylvania wells; but in Indiana these substances occur in a limestone.

Ore Deposits. — Some of the metals which occur in the earth possess qualities which make them useful to man; and, as we know, great effort is made to obtain them. Iron, gold, silver, copper, etc., serve us in many ways. In the earth they generally occur in association with other elements, in the form of minerals; and when mined, these have first to be separated from their companion minerals, with which they are *mechanically* mixed; and then it is usually necessary to separate the metal from the elements with which it is *chemically* combined. Therefore in obtaining these substances from the earth, many complex and often very costly methods are employed. In order that this may be profitable, the ores of the metals must occur in a somewhat concentrated condition, and they must be in a place from which they may be obtained without too great expense. Thus a copper mine that would pay in New England or New York, might not be profitable if situated among some of the nearly inaccessible

mountains of the west. Where the deposit is very rich, it is often profitable to tunnel into the earth to a depth of several thousand feet.

Ores occur in the rocks of the crust under many different conditions. Sometimes the ore is a native metal, as is the case with most of the gold which is mined; but more commonly it is a simple compound of a metal. It would be quite impossible to state in a few words the various ways in which the ores occur, and only one or two of the most common kinds can be described, and these only in a general way.

Some of the ores have been deposited in beds, by a process of *replacement*. That is, some mineral or rock, such as quartz or limestone, has had its place taken by the ore,—this being deposited bit by bit, while the water which carried the solution took away an equal amount of the original mineral. This resembles the replacement of wood tissue by silica—a process known as *petrefaction*. Some ore deposits represent the mere gathering together of substances into bunches, known as *concretions*, the cause for the accumulation being still unsolved.

Much more commonly, ores are deposited in some cavity in the earth; and the most common of these is the fissure which accompanies faulting. In this break in the strata, which often extends to great depths, ore is deposited from solution in water. This underground water is often highly heated, and contains in solution alkaline or acidic substances which give to it great power of dissolving and altering minerals. By complex chemical reactions, which are not well understood, these ores are deposited in *veins*, usually in bands, and commonly associated with other minerals which are not of value. Even ores of gold or silver are frequently deposited in this way.

Another important way in which ores occur, is in surface deposits of sedimentary origin. For instance, when a gold-bearing rock decays, the nearly indestructible gold resists weathering ; and being a heavy substance, as it is being washed down toward the sea, it tends to accumulate on the stream bottom, forming what is known as *stream* or *placer* gold deposits. This is the condition in which a great deal of the gold of the world has been found ; and this precious metal occurs in such deposits in the west, in Siberia, Australia, and many other places. Both tin and platinum are also found in a similar condition.

Distribution of Ore Deposits.—The valuable ore deposits which are found in fissures, are not present in all parts of the crust ; but for the most part they are confined to mountainous regions. The Cordilleran region of the west is a most striking illustration of this ; for these mountains form the most remarkable mineral district of the world. While this district produces only a few of the metals, it is not because the others (such as iron) are absent, but because in that region the conditions are too unfavorable for the extraction and marketing of those which are not very valuable.

The reasons for the great importance of the Cordilleras in the production of metals, are mainly two. In the first place, among these mountains there are many faults, and other cavities, in which ore may be deposited. There are also numerous volcanic rocks of recent date, a point of considerable importance. The heat from these lava intrusions furnishes to the underground water a temperature sufficiently high for important action. Probably even at present some of the hot springs of that region receive their heat from buried lava intrusions ; and probably also, mineral deposits are being made in their tubes at a considerable distance from the surface. A second reason why the presence of igneous

rocks aids in ore formation, is that there is a larger percentage of metals in these than in others. Therefore water which is percolating through and altering them, finds a greater supply of metals for solution than would be the case if passing through most sedimentary rocks.

Mineral Wealth of the United States. — Mainly because of the Cordilleras, the United States is the great mineral country of the world. Of the following metals it produces more than any other country: gold, silver, iron, and copper, which are the most important of metals; and in the production of lead, zinc, and mercury, it holds second rank. Its output of coal is greater than that of any other nation excepting Great Britain, while no other country supplies so much petroleum and natural gas. In some of the minor substances it also holds a high rank. Indeed, we produce nearly every important mineral substance found in the earth's crust; and usually our production is very great.

The importance of the mineral industry of this country, is shown by the fact that in 1892 the mineral production was valued at nearly \$700,000,000, of which about \$300,000,000 came from the metals, — mainly iron, silver, gold, copper, lead, zinc, and mercury. For the most part this represents the crude product; and in the utilization of this in manufacturing, there are industries also worth many hundred millions of dollars: so that, directly and indirectly, the mineral industry of the country is one of the most important.

The few facts that follow, will serve to furnish an idea of the distribution of this product. According to the census, the leading mineral state is Pennsylvania, which produces more coal, petroleum, gas, and stone, than any other state. In 1889 the value of its product was \$150,000,000. Second in rank is Michigan, which produces most iron and salt, and is the second in the production of copper. Then comes

Colorado, which leads in the production of silver and lead, and is second in the production of gold; and Montana follows, leading in the production of copper, and second in the output of silver. The east excels in the production of non-metallic substances, and the west in metals.

This astonishing mineral wealth has, in no small degree, been responsible for our development as a nation; and there are still great undiscovered stores. There seems to be almost no limit to the possibilities in this direction, and our Alaskan territory promises to add to this wealth. Nature has been most prodigal in lavishing her favors upon this country, for she has given us nearly all that man could request: great variety of climatic conditions, an almost infinite variety of topography, a soil wonderfully rich over a great area, a forest covering from which we have been able to draw heavily for over a century, water power for the mills, harbors for the commerce, mineral deposits of marvelous wealth,—these are things which mark our country as one of great possibilities, and which have made possible our present prosperity, and upon which we may predict so much for the future.



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APPENDIX I.

METEOROLOGICAL INSTRUMENTS, APPARATUS, AND METHODS.

By instruments we are able to measure the temperature, pressure, wind force and direction, rate of evaporation, percentage of moisture in the air, amount or percentage of sunshine, rainfall, and other weather phenomena. In order to understand these instruments, it is necessary to handle them just as the meteorological observer does. Mere description can serve only to explain the principle upon which they depend.

Thermometric Records.—In measuring the temperature, use is made of the principle that certain substances expand when heated and contract when cooled. Ordinarily it is more convenient to employ a liquid, and that best adapted to this purpose is mercury. However, where temperatures below the freezing-point of mercury are liable to be experienced, alcohol is used.

The *thermometer* is graduated into degrees according to some scale, and different scales are employed, the most common in use being the Fahrenheit, which is adopted in nearly all English-speaking countries, and is used in this book. The two points of importance in the Fahrenheit scale are the freezing-point, which is placed at 32° , and the boiling-point, which is placed at 212° . In the Centigrade scale, the principle is the same; but in this case the degrees are larger, the freezing-point being placed at 0° , and the boiling-point at 100° . Therefore, in converting the Fahrenheit to the Centigrade scale, 1° of Centigrade is equal to 1.8° of Fahrenheit, and to this must be added 32° . All are familiar with thermometers, and the principle upon which they depend is easily understood.

Much care is needed in the construction of a good and accurate thermometer, and there are some cheap and very inaccurate instruments. This is one reason why the observations of temperature made by different

people may vary so widely, even though made in almost the same location. Another very important reason for this difference is the fact that the thermometer is not always wisely placed. In order to obtain a true measure of the temperature of the air, it is necessary that neither the sun, nor any warm body on the earth, shall influence the air whose temperature is to be measured. At meteorological stations, the thermometers are placed in a *thermometer shelter*, which consists of a frame, open so that the air may pass through it, and yet sufficiently closed to prevent the sun's rays from striking upon the thermometer. This is raised about 10 feet from the surface, and is placed away from buildings.

Of late, metallic thermometers have come into use; and these depend upon the effect of heat and cold on metal strips or springs enclosed within a clock-like case. They are not so accurate as the well-made mercurial thermometers, and their chief value is in obtaining a continuous record. The self-recording thermometers, or *thermographs*, are mostly of this class. As the metal expands or contracts, it causes an index hand to move back and forth over a dial, and upon this index, a pen or pencil may be fixed in such a manner as to press against a sheet of paper. As the temperature rises and falls, the needle is made to move backward and forward, and therefore the pen is also moved over the paper. For the purpose of obtaining a record of the time at which these changes occur, the paper itself is also made to move by means of a clock-work attachment; and therefore a record of all the temperature changes throughout the day, may be automatically registered.

It is often found desirable to have a record of the *highest* and *lowest* temperatures of the day made by a mercurial thermometer. For this purpose the *maximum* and *minimum* thermometers are used, which, by a special contrivance, record the very *highest* and *lowest* temperatures of the day, but do not give any record of the *time* at which these occurred. The thermometer itself gives us a record of the *air temperature*, which is very different from the *energy* which comes from the sun. If the bulb of a thermometer be blackened by black paint or lampblack, and the instrument be placed in the direct rays of the sun, it is found that the temperature rises very much higher than in the case of a thermometer in the shade, or even of a natural thermometer exposed to the sun's rays. Such an instrument is known as the *black-bulb thermometer*.

Barometric Records.—The air has weight, and at the sea level this weight, or *air pressure*, averages approximately 15 pounds on every square inch. The air pressure at any given place is liable to many varia-

tions, and it is the purpose of the *barometer* to detect these changes. The principle of the barometer is that a column of air will exactly counterbalance a column of equal weight of any liquid. Thus water in a vacuum will be made to rise to a height of about 32 feet. In other words, it counterbalances the pressure of the air, and the pump is based upon this principle, water being forced into the partial vacuum caused by pumping. We could use a column of water for a barometer just as well as mercury, which is ordinarily used; but such a barometer, since it would need to be at least 35 feet in height, would be most unwieldy. The mercurial barometer consists of a tube of glass, sealed at one end and partly filled with mercury. Above the column of mercury is a practical vacuum, and the lower part of the tube is immersed in a cistern of mercury. As the air pressure varies, the mercury is caused to rise in the tube, or to descend from it into the cistern; and when the air is heavy, we speak of a *high barometer*; when it is relatively light, of a *low barometer*. In meteorology, these terms have come to be synonymous with *high pressure* and *low pressure*.

The tube of the instrument is graduated in inches, and at the sea level the average height of the mercury in the barometer is about 30 inches. The method of reading the barometer, and the use of the vernier scale, can be understood only by handling an instrument.

Several forms of *barograph* are employed to convert the record of the change in pressure into graphic, continuous records. The rising and falling column of mercury may be automatically photographed, or the rise and fall of the column may be recorded by electricity; but most commonly some form of *aneroid barometer* is employed. The aneroid depends upon the effect of air pressure upon a metallic diaphragm; and as the index hand moves one way or the other, it carries a pen, which marks the changes upon a sheet of paper revolving on a cylinder, just as in the case of the self-recording thermometer.

Measurement of Wind Direction and Force. — To-day the *direction* of the wind is measured in very nearly the same manner that it has been for centuries. The *wind vane* is a familiar feature. The *force* of the wind, or its velocity, may be roughly estimated by any observer. A statement that the wind velocity is 40 miles an hour, means that in one hour the wind travels that distance. For accurately measuring this velocity, an instrument known as the *anemometer* is used. It consists of four cups, fixed upon a cylinder, which are revolved by the wind at rates depending upon its velocity. The air enters these cups and whirls them about,

very much as water enters a turbine wheel and causes it to revolve. By means of a series of wheels, each revolution of the anemometer is recorded, and this may be transmitted by electricity to some place where an automatic record is kept in miles per hour.

Measurement of Evaporation.—The measurement of evaporation is made in inches of water evaporated from a surface exposed to the air. Almost any dish can be used, and the scale of inches be marked upon it; or the measurement may be made with a graduated rule. Since the rate of evaporation varies with the temperature, it is best to attempt to imitate natural conditions as nearly as possible, though this is not ordinarily done. The best way is to place the evaporating pan in a quiet body of water, allowing it to float on the surface. There are various contrivances for obtaining a continuous record.

Measurement of Moisture in the Air.—The measure of the *relative humidity* is often obtained by the *hair hygrometer*, which is a bundle of human hair from which the oil has been extracted. As the amount of moisture in the air increases, the hair absorbs more and more, and as it does so, expands; and, since one end is fixed while the other moves freely, this expansion may be made to record itself against a graduated glass scale.

The best method is that of the use of the *sling psychrometer*. This instrument consists of two thermometers fixed side by side upon a board. One is an ordinary thermometer, the other has a piece of wet muslin placed around its bulb. The instrument is whirled in the air, and the water evaporates from the wet muslin, the rate of evaporation varying with the humidity of the air. If the air is very dry, evaporation takes place rapidly; if damp, it proceeds with slowness. Since evaporation produces cold, the temperature of the wet bulb thermometer descends lower than that of the ordinary thermometer. By reading these two records of temperature, the relative humidity of the air is readily determined by means of a series of tables which are constructed for and furnished by the Weather Bureau at Washington. The relative humidity is expressed in per cents between 0, which is perfectly dry air (a condition which never occurs), and 100, which is saturated air. From this measure the dew-point may also be determined.

Study of Clouds and Sunshine.—Various instruments are used to obtain a record of the amount of sunshine, and these may be found described in the books referred to at the end of this Appendix. Much work of a scientific nature is also being done in the study of clouds, in-

cluding the measurement of height, the photographing of cloud forms, etc. We cannot devote space to a description of these.

Measurement of Rainfall. — By the *rain gauge*, rainfall is measured in inches, an inch of rainfall being an actual inch of water which has fallen upon the surface. This is a cylinder having a broad, funnel-shaped top, with the outlet to the funnel extending into an inner cylinder. The water falls upon the surface of this funnel, and runs into the inner cylinder; and the proportion of this to the surface of the funnel is as 1 to 10. By this means the actual rainfall is magnified 10 times in the inner cylinder, so that light rainfalls may be readily measured.

The snowfall is often measured in the same instrument; and in order to express the snowfall in inches of rain, as is usually done, the snow that is collected in the cylinder is melted. About one inch of rain is equal to 10 inches of snow; but in this there is much variation, for some snows are composed of very compact crystals, while others are light. In some cases the *depth* of the snow is measured and divided by 10, in order to be reduced to inches of rain. This is roughly correct.

Self-registering rain gauges are made, the record of rainfall being kept either by means of a float that rises as the rainfall increases, or else by means of a pair of scales upon which the rain gauge is placed.

Meteorological Methods and Results. — At present, nearly every civilized nation has a weather bureau from which are issued weather maps and predictions. In the United States the central bureau is at Washington, and many of the states have similar bureaus. The national bureau issues daily maps and other publications describing or predicting the weather.

The information obtained in this way is of much value. The predictions of the Weather Bureau are very closely followed by the masters of sailing vessels, and much loss of life and property has been prevented by this means. Predictions of excessively cold weather, and of storms, give much information concerning the weather changes that are liable to occur; and by means of the warnings farmers are sometimes able to prepare against unusually early or late frosts.

For the purpose of obtaining information which shall serve as a basis for predictions, the Weather Bureau has stations distributed over various parts of the country, at which observers read the records of the several kinds of instruments. These observations are made at regular times during the day, and the results are telegraphed to central stations, where they are all worked over and plotted upon a map. Then, with the

knowledge of the changes that have occurred in the preceding days, and knowing what changes are liable to follow, predictions of greater or less accuracy are made, in some cases for several days in advance. In many respects these predictions are of great importance; but in addition to this result of the work, we are rapidly obtaining much scientific information concerning the air. We are also obtaining many facts relating to the general climatic features of the country, and of the world. But in these directions much less is being done than should be; for until we know more about the air and its behavior, we may not expect to obtain more accurate predictions.

Upon a weather map (Fig. 46) the wind direction is plotted in the form of a series of arrows pointing in the direction toward which the wind is blowing. The temperature is also placed upon them, and lines of equal temperature, or *isotherms*, are drawn across the country. The pressure of the air is also graphically shown on the maps by a series of lines which are known as *isobars*, or lines of equal barometric pressure, each tenth of an inch being represented by an isobar. The *amount* of rainfall at the different stations is printed on the maps. Thus at a glance one may see the weather conditions of a whole country; and by studying a series of these maps made for several successive days, one is able to trace the variations in weather conditions for different places.

REFERENCE BOOKS.

Waldo. — MODERN METEOROLOGY. (Contemporary Science Series.) Scribner, New York, 1893. 12mo. \$1.25.

Russell. — METEOROLOGY. Macmillan & Co., New York, 1895. 8vo. \$4.00.

Abbe. — TREATISE ON METEOROLOGICAL APPARATUS AND METHODS, Annual Report U. S. Signal Service for 1887. Part II. Washington, 1888. There is also a description of instruments in the first part of the Annual Report of the Weather Bureau, 1891-1892.

For obtaining the Dew-point and Relative Humidity, see THE TEMPERATURE OF THE DEW-POINT, etc., U. S. Signal Service, 1889.

For all kinds of Meteorological Tables, see Guyot, TABLES: METEOROLOGICAL AND PHYSICAL. Fourth edition, 1884. 8vo. Smithsonian Miscellaneous Collections, Washington. \$3.50.

APPENDIX II.

TOPOGRAPHIC MAPS.

The study of the land is greatly facilitated by the use of maps, and for this reason some space may be devoted to the description of the more common kinds of topographic maps. By far the best means of representing land irregularities is the *model* (Fig. 266), upon which elevations are shown as elevations, so that one sees the actual land forms in relief, although one gains an exaggerated idea of the relation between the vertical and the horizontal. Unfortunately, the expense of preparation of a model is too great for its common employment.

In some instances, elevations are shown by means of shading, this being known as the *hachure* method. By a series of lines, the actual

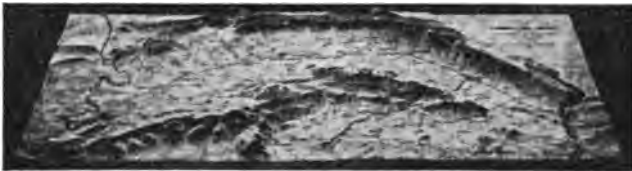


FIG. 266.

Model of Cumberland Valley, Pennsylvania.

elevations are made to appear to rise above the rest of the country, while the depressions are shown in their natural relation to the high land. This method is used by the United States Coast Survey in charting the coast line of the United States (Fig. 267), and it is employed in some of the European countries. Its effect is very vivid; but one disadvantage is, that while the *differences* are shown, one does not find information concerning the *actual* elevations expressed in feet.

The *contour* method is extensively used, and is employed in the large scale map which is now being prepared of this country. While from the artistic standpoint it is not so effective as the *hachure* method, it is

superior to this in many respects. A *contour* is a line of equal elevation. It is the line to which the sea would rise if the land were depressed to the depth represented by the height of the line. If we imagine ourselves near the seashore, the coast line is then the contour line of 0, and the 100-foot contour line is that to which the sea would reach if it were raised just 100 feet.

The contour map (Figs. 150, 190, 228, and Plate 25) is made upon a horizontal scale which varies in different cases. In this country the usual scale is one inch to the mile; that is, every mile of country is allowed one inch. No allowance is made for the vertical element of the country. Thus if a region of considerable irregularity is being mapped, an inch on the sheet is made to represent one mile in a horizontal direction. As one stands upon the side of a hill, and looks across a valley to another hillside at the same elevation, and a mile distant,

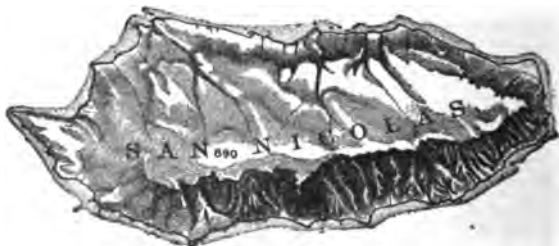


FIG. 267.

the horizontal line is just one mile in length; but if the observer should start to walk from the place where he stood, to the point to which he looked, he would need to travel considerably more than a mile. On ordinary maps this greater distance is not shown; but on the contour maps it is brought out by means of the contour lines. The inch represents the horizontal mile. Each descent or ascent finds a representation in the contour lines; and if they are close together, one sees that the vertical distance to be traveled is very great.

There is much difference in the scale of elevation represented by contour lines. On most of the maps in the eastern part of the United States, every 20 feet of ascent or descent is represented by a contour line, and we speak of this as the *contour interval*. Let us suppose ourselves passing over an irregular country. Imagine that we are to travel a dis-

tance of one mile, in the course of which we go down into one valley, up the hillside and down into another valley. The entire area on the map would be represented in the space of one inch. If the first valley had a depth of 200 feet, and the contour interval were 20 feet, on the map representing this area there would be 10 contour lines, which would need be very close together, because the descent of 200 feet in the small fraction of a mile would necessarily be rather rapid. If the hill over which we pass rises 40 feet above the valley bottom, we would ascend over a distance represented on the map by two contour lines,—a rather moderate ascent. If the valley on the opposite side of the hill should happen to be 400 or 500 feet in depth, the descent would be extremely precipitous; and it would be necessary to represent this steep declivity by so many contour lines that one would merge into the other, and there would be a mass of crowded lines.

From the several sections of contour maps (Figs. 150, 190, 228, and Plate 25, reproduced diagrammatically), one is able to understand the meaning of the contour lines, and to discover the irregularities which they represent.¹



REFERENCES.

Nearly every European government is publishing a topographic map, and among these are to be found many excellent illustrations of land forms. In this country, the entire area of Massachusetts, Rhode Island, New Jersey, and Connecticut is now mapped, and teachers can obtain these from the Commissioners of the Topographic Map at the state capital. In all of the other states there are maps of some districts; and copies of these may be obtained from the U. S. Geological Survey. During the year 1895-96 the Survey will issue, at a small price, a few of their most instructive maps with descriptive text.

The seacoast maps of the U. S. Coast Survey are excellent and cheap. The same is true of the maps of the Great Lakes, the Mississippi, and the Missouri. A very important pamphlet ("The Use of Governmental Maps in Schools," Davis, King and Collie, Holt & Co., New York, 1894, \$0.30) has been prepared for the purpose of indicating useful topographic maps. The methods used in making the maps of the Geological Survey are described in Gannett's *MANUAL OF TOPOGRAPHIC METHODS*, Monograph XXII., U. S. Geological Survey, Washington, 1893. 4to. \$1.00.

¹ Specimen maps may be obtained from the U. S. Geological Survey.

SUGGESTIONS TO TEACHERS.

In the preparation of this book, the endeavor has been to state the subject in a purely descriptive manner. Nevertheless, the best way to learn physical geography is not to read about it, but, so far as is possible, to work out the points for one's self. Not merely does the laboratory method teach the subject better, but it trains the mind of the student in a far more valuable way than is done merely by acquiring information from a book. The following notes are appended merely as suggestions concerning the way in which simple laboratory methods may be introduced. There is very little *necessary* expense attached to the introduction of these methods; but of course by the acquirement of other and more expensive materials one can improve the teaching almost without limit.

Each teacher will need to work out the details of the problem for himself; for the environment, the available materials, the time that can be devoted to the subject, etc., are so variable that at present it would be difficult to outline a course of even general value. I would urge upon every teacher the importance of introducing *some* laboratory work; for it will stimulate the interest of the student, particularly if he is brought in contact with the real phenomena of nature. The land and the air are always available and full of lessons: to some, the ocean or the lake shore may also be within reach. I am so much interested in having these methods introduced that I invite teachers to correspond with me, if I can aid them in obtaining materials for teaching purposes.

CHAPTER I. — Laboratory work in illustration of this chapter is not easy. Still, the best way which I know to give the student a clear idea of the relation of the several members of the solar system, is to have each student construct a rough model of it. This can readily be done by means of fine wire and pasteboard. By merely coiling the wire on the desk, each of the orbits can be made in its proper relation to the others. Then each planet can be made from pasteboard, the size representing a slice cut along the equatorial diameter. In order to have this produce the most

good, the scale, or relative sizes and distances, should be true to nature. Upon these orbits, the bodies can be made to revolve and to rotate, so that some idea may be obtained concerning the relative movements of the bodies. The relation of the moon and earth may be studied in the same way.

In order to show the movements of the earth and the cause of seasons, an excellent method is to construct an orbit of wire and cause a sphere to move around it, the sphere rotating as it revolves. There are various ways in which this may be done; a permanent orbit may be constructed in the schoolroom, and a large ball, or better a globe, may be carried around it, each student being allowed to stand near the center, as if he were in the position of the sun. Each student might be allowed to construct a smaller orbit and study the earth movement himself. Celluloid spheres are very inexpensive, and upon them the continents may be roughly outlined, while an axis is passed through them to represent the position of the poles. An exercise or two conducted along lines something like the above will do more to teach the students the relations of the bodies of the solar system than a score of lessons from the book; and many students go through a course in astronomy without a proper conception of the solar system. The teacher will see many means of adding to this if more time can be spared. Thus it is possible to show the relations of the comets to the solar system; the immensity of the distance to the stars; the size of the sun; aphelion and perihelion; apogee and perigee, etc.

CHAPTER II. — The teacher of physics will find many opportunities for illustrating this chapter by laboratory methods. Thus the various effects of heat and light are capable of very graphic illustration. Convection may be illustrated by heating dust or smoke-filled air in a cylinder. Refraction is readily shown by the prism, and nearly all of the principles of light and heat may be illustrated. Compression of air can be very readily shown. Saturation of air may be shown by placing water in the bottom of a cylinder; and then if the air temperature is lowered, some of the water vapor may be condensed on the sides of the vessel. The various ways in which humidity is increased or decreased can be studied in detail by each student; and they can be given hypothetical cases from which to draw conclusions concerning the condition of the air which necessarily follows.

The difference in the length of the summer and winter days is readily illustrated by the use of the globe and a candle. By placing the candle

in different positions, so as to throw the rays at the angles at which the solar rays reach the earth, and by causing the globe to revolve, this is easily seen by the students.

CHAPTER III.—In illustration of this chapter, laboratory work may be introduced by stating the latitude of a place and having the students tell the probable temperature conditions. Then add the altitude and have them state what modifying effect this would have. After this the position with reference to the sea may be given, and each student ought to be able to state the approximate conditions of temperature. They could be given prominent cities in the world, and have for their problem the determination of the temperature, for which purpose it would be necessary for the student to first ascertain their position, altitude, etc., and this would also serve to teach geography. On the other hand, given a set of temperature peculiarities, the students can determine what parts of the world experience them, and why this is so. The teacher can tell the student of differences between places on the same latitude, or of resemblances between points on different latitudes, and call for an explanation of these. Much similar work may be introduced if the time allows; and it is safe to say that not only will the interest be aroused, but the habit of logical thought will be improved.

Each student can construct a daily curve from personal observation, particularly if a maximum and minimum thermometer are available. With either fictitious or actual data, they may construct a seasonal curve. Placing a maximum and minimum thermometer in the ground at a depth of one or two feet, the difference between the range of air and earth temperatures is very vividly impressed upon the mind. In order to make this even more striking, temperature observations should be kept at the surface of the ground, and at an elevation of about 10 feet. These differences are best shown in warm weather.

A study of the isothermal charts furnishes opportunity for observation and deduction, particularly if Buchan's charts (see p. 84) can be obtained. The student can construct an isothermal chart from data given and averaged for several places, either for the state, or the country, or for the locality near the school. For these and other purposes in which maps are needed, the set of cheap outline maps published by Heath & Co. of Boston, or Rand, McNally & Co. of New York, are valuable. Maps of all the states and territories can be obtained. The data of temperature, etc., for these purposes may be made arbitrarily; but it would be better to use the tables which can be found in the *Annual*

Reports of the Weather Bureau. In some states, as for instance in New York, climatic data will be found in the State Weather Reports. These and the national reports may probably be obtained free of cost, provided a statement is furnished of the object for which they are needed. One report will last for many years. With these data, temperature ranges and other illustrations may be graphically plotted by the students. The amount of laboratory work possible in this and other subjects far exceeds the time that will be available in most schools.

CHAPTER IV. — After studying the general features of the atmospheric circulation, the students should be able to construct a summer and winter wind chart for the Pacific, — of course attempting only the general features. Upon the charts of the Atlantic, there are many problems which have not been mentioned in the text; and a thorough examination of the wind charts will be valuable. The Challenger charts by Buchan (see p. 84) contain much of value on the winds of the globe. As an instance of how observation and deduction may be brought into the study, the following might be suggested as a fair question: What conditions result in the two opposite seasons in the belt where the doldrums and the trade winds overlap?

The student should note the relation between wind and barometric conditions. The daily weather charts¹ are valuable for this study; and the student can also make his own observations with barometer, thermometer, wind vane, etc. A particularly valuable study can be made with the weather maps. By examining a series of such maps, one may observe the force and direction of the winds, and the progression of the conditions favoring certain winds during the successive days.²

When studied with reference to the conditions prevailing in its home region, this method becomes of much value. In this way the student can come into the possession of a knowledge of the causes for the winds that are common in his section, as well as the relation of these to the winds of the surrounding country. Observations on approximate wind force and direction can easily be made by each student; and this will serve as a basis for a comparative study of the daily weather maps. Before the map of the day is shown them, they should be able to approximately foretell the probable conditions, on the basis of a series of simple observa-

¹ The teacher can probably have these sent by mail to the school.

² The semi-daily maps are of especial value for this purpose, and some of them may undoubtedly be obtained by applying to the Weather Bureau.

tions on the wind, temperature, and pressure. Such a study will create a real live interest, and make the students observers of the things of every-day occurrence, as well as train their minds to the habit of drawing logical conclusions from a series of observed facts.

CHAPTER V. — The study of cyclones and anticyclones receives much aid from the daily weather maps. On these the student will see the form and size of the areas, their rate and direction of progression, the amount and distribution of rainfall, the direction of the winds, their spiral tendency, the left-hand whirling, etc. He will observe how the winds change from day to day, and what relation they bear to the areas of high and low pressure. He can predict the changes and study them in connection with the weather of his own immediate neighborhood. The storm paths and their irregularities can be studied with the aid of the *Monthly Weather Reviews*.¹ From the weather predictions, and the printed notes on the map, the relation between the cyclonic areas and thunderstorms is readily seen. The *Coast Pilot*² for the fall months, often contains valuable material for study in connection with West Indian hurricanes.

CHAPTER VI. — The student can be directed in the study of the formation and movement of clouds, and their relation to rainfall and temperature. Reports upon these observations, from time to time, will stimulate them to a deeper interest in cloud formation. Attention can be directed to the possibility of predicting weather changes by an examination of the clouds. This furnishes an excellent opportunity for bringing the student into contact with nature. A study of the rainfall charts,³ in connection with those of temperature and wind, will give opportunity for the explanation of many peculiarities of rainfall distribution. Careful observation concerning the rainfall of the place where the student lives will be of value in showing the irregularities in amount, as well as in occurrence. Let him compare this with that of the doldrum belt.

A sling psychrometer (see Appendix I.) may be readily constructed from two thermometers, and the relative humidity of the air be determined. From this the student can be taught to predict the occurrence of dew or frost for the succeeding nights. The value of these lessons will be greatly increased if the students are called upon for reports. If the pre-

¹ These also may probably be obtained at Washington upon application.

² Distributed free by the Hydrographic Bureau of the Navy Department.

³ Those recently published by the Weather Bureau are very valuable.

dictions that are made are not fulfilled, perhaps the reasons will be apparent; and there may have been dew at one place and frost at another, or dew at one home and none at another. Then the explanations for these differences can be obtained from the students.

There are few better ways to train the habit of observation than to tell the students to look for certain things, giving enough directions so that they may be led to observe. If too little guidance is given, all but the brightest will be appalled by the difficulties; for one of the least developed parts of the student mind is generally that which directs the eye to look for details, and then to put these details together into a connected whole. I have often noticed how pleased secondary school students have been when their teacher has told them to look up something, and with what earnestness they have worked to have correct answers. They like to be made to feel that they are using their own minds; and it is a distinct relief from the monotony of learning what the book says. Since they are in constant contact with the problems of physical geography, each day can be made to yield opportunity for observation; and nothing could be more profitable than to give the class a daily task in observation, devoting a part of the recitation hour to a discussion of the results.

CHAPTER VII. — Many of the suggestions made for the previous chapters will apply to this; but there are many ways in which these may be put together for a whole. The probable conditions of weather and climate in various parts of the earth may be inferred by a study of the charts of temperature, wind, and rain. The country near the school may furnish illustration of local differences in climate.

CHAPTER VIII. — There is of course much opportunity for an enlargement of this subject; but it would come better under a study of zoölogy and botany. The object sought in this chapter is to point out the relation between climate and life, and to show also that the land itself presents certain obstacles to the spread of life.

CHAPTERS IX., X., AND XI. — Unless the student dwells by the seashore, there is little of value to be obtained from an attempt at observation study in the topics covered by these chapters. The charts may be studied, and reasons found for the peculiarities exhibited. If the charts of the Challenger Reports are available, particularly those accompanying the two final volumes of Summary, there will be found much opportunity for laboratory study. By a careful examination of the charts of the ocean bottom, much can be learned concerning the topog-

raphy of that large part of the earth's surface which is submerged beneath the ocean.¹

One or two visits to the seashore for the purpose of studying the rise and fall of the tide, the action of waves, the distribution of life along the coast, etc., will be of great value. Even upon the shore of a lake some of these features may also be illustrated. The distribution of cold and warm water by the ocean currents, furnishes much opportunity for study in connection with climate.

For tides, the "Tide Tables" (see reference at end of Chapter XI.) give data for a very interesting study. The rise and fall of the tide is stated for various places; and if the student is told to construct a diagram similar to Fig. 86, which is based upon these tables, he will learn much about the rise and fall of the tide. At the end of that book the phases of the moon and the times of perigee and apogee are stated, so that the reasons for many of the more important tidal variations will become apparent after a little study and thought. Taking the various stations for which the tidal predictions are tabulated, and locating them upon a map, one sees the geographic reasons for the difference in tidal height from place to place; and given a place with a certain geographic location, the student can apply these principles to the approximate determination of the tidal conditions. There is no better way to impress upon the student the peculiarity of tidal movement, than to have him laboriously construct a chart of these movements. For students of the interior, this is less important than for those who dwell near the sea.

CHAPTER XII. — There is almost no limit to the opportunity for field and laboratory study upon the topics briefly outlined in this chapter, though it more properly falls to the province of geology.² Photographs of various phenomena, as well as lantern slides made from them, are now easily obtained.³ An excellent method is to project a view upon the screen, and call upon students for a description of the phenomena illustrated. This has the great advantage of placing an enlarged picture before the class, so that each student may see every feature; and this does away with the necessity of many duplicate pictures with one in the hand of each student. Where the latter method is employed, cheap

¹ The Jones relief globe, sold by A. H. Andrews & Co., 215 Wabash Ave., Chicago, Ill., for \$100, is of great value in this connection.

² The study of geology could very properly be introduced here as a part of physical geography.

³ The author will be glad to advise teachers who wish to obtain these.

blueprints may serve admirably as substitutes. With the widespread introduction of electricity, it is now possible, in many schools, to make use of the electric lantern, which may be used in a room only partially darkened. Much can be done by asking the students to describe the features illustrated in the pictures in the book. Several phenomena are often illustrated in the same view.

By far the best way to study the phenomena of the earth's surface is to see the actual thing; and there are usually opportunities for some such study near the school. In most cases the teacher can find some phenomena of geology, such as igneous or sedimentary rocks, fossils, folds, etc. The students will enjoy and profit by field excursions.

Collections of the common minerals and rocks can be bought for a few dollars;¹ and more will be learned by an hour's study of such a collection, than by weeks of study from the books. Some of the common rocks and minerals may usually be collected near the school. The teachers in those schools which are located within the glacial belt will find a storehouse of rock specimens in the clay and gravel banks. All of the common rocks, and many of the minerals, will often be found there. If the students can be sent or taken out for the purpose of making such collections, they will soon learn a great deal about rocks; and this plan will be found admirable, even if the school has complete collections.

CHAPTER XIII.—In most places the phenomena of erosion and weathering can be studied in the field. Rock specimens exposed at the surface will show the destruction in progress; and upon exposed bluffs many instructive lessons may be studied. A journey in such a place will be found to be most profitable; and the students will see important things that the majority of the world pass by without ever noticing. A visit to a spring may prove of value; and if it chances to contain iron, or other substances, in solution, chemical action of water becomes something more than the mere book statement.

In most parts of the country, wind and glacial action cannot be illustrated by actual examples. Upon the lake shore, or better upon the sea-shore, wave action may be studied; and in practically every part of the country, some form of river and rain erosion may be seen. Let the teacher have the students watch the rills and brooks and report upon the change in amount of water and sediment. This will train their

¹ Ward's Natural Science Establishment at Rochester, N.Y., and E. E. Howell, 612 17th St., N.W., Washington, D.C., have such collections.

powers of observation and arouse their interest; and the skillful teacher may make this the basis upon which to build a real understanding of the action of rivers. The key to success in this direction is to *tell* the student only so much as is absolutely necessary, but to make *him* tell the story, not from memory of what the book says, but upon the basis of a series of observations which *necessarily* lead to these conclusions.

It is not necessary to find illustrations of all phenomena in the field, though the more, the better; but the object is to teach the student *how* to see for himself, so that he may see other illustrations whenever he happens to come upon them. Where it is not feasible to study the phenomena in the field, photographs or lantern slides make a fair substitute.

CHAPTER XIV. — With a set of Physical Maps¹ of the continents, there is opportunity for study of the grander features of the land. These are much more naturally shown upon a relief globe.² The distribution of mountains, continents, seas, etc., are there shown very vividly. Particularly is this the case in the second model, for here the ocean waters are not present to obscure the topography of the bottom of the sea.

The larger features of the United States may be studied on the nine-sheet contour map published by the U. S. Geological Survey; and also upon the smaller shaded relief map published by the same bureau.³ Better still, if the school can afford it, a *model* of the United States should be obtained.⁴ With these aids, a good knowledge of the geography of the world can be obtained, and at the same time much training be gained, for the teacher will find ample opportunity to suggest problems for the pupil to study and answer.

CHAPTER XV. — In many parts of the country, particularly within the glacial belt, two types of river valley may be seen within a short distance of the school; and everywhere in the field it will be possible to see illustration of some stage of river-valley development. The teacher can make such an excursion, or series of excursions, the basis for an expansion of the subject of river-valley development. Where these features

¹ The Kiepert maps are sold by most large dealers in school supplies. Rand, McNally & Co. of Chicago and New York advertise a similar set.

² Such as that sold by Rand, McNally & Co. of New York, or the Jones globe (see suggestions for Chapter XI.).

³ The latter accompanies the Thirteenth Annual Report of the Survey.

⁴ E. E. Howell, 612 17th St., N.W., Washington, has a model of the country for \$125, and a smaller one for \$25.

are not well illustrated, recourse may be had to photographs or lantern slides.

A study of topographic maps will be found of great value in this connection, as well as in illustration of the features described in the following chapters. For suggestions concerning the special maps needed, and their use, see the pamphlet by Davis, King, and Collie, referred to at the end of Appendix II.

CHAPTER XVI. — Here again there is the possibility of finding illustrations in the field, and a certainty of finding them in photographs and slides. The U. S. Geological Survey topographic map of Niagara (free), and the Lake Survey map of the same (United States Engineer Office, 34 W. Congress St., Detroit, Michigan; \$0.20), are very useful. The latter bureau publishes a number of charts of the Great Lakes; and on the Geological Survey maps, notably those of New England, many illustrations of glacial lakes and swamps will be found. The Mississippi delta is well illustrated on the U. S. Coast Survey chart 194. For flood-plain peculiarities, see particularly the maps published by the Mississippi and Missouri River Commission, whose headquarters are at St. Louis, Missouri. For facts concerning these maps see the pamphlet by Davis, King, and Collie, referred to at the end of Appendix II.

CHAPTER XVII. — The effects of glaciers upon the surface of the land may be partly inferred from the study of a series of topographic maps of places within the glacial belt, and a comparison of these with some from outside of this belt. This may be very well supplemented by views from the two regions; and then, if the school is situated within the glacial belt, by excursions¹ to glacial deposits. These will be of great value for the illustrations of many points. In all of these cases, the teacher should have the students observe as much as possible, and should avoid telling them things which they ought to be able to see for themselves.

CHAPTER XVIII. — A teacher who has given no attention to the subject, will be astonished to find how many lessons can be learned by an hour's tramp on the shore of a lake or the ocean. The beaches and cliffs are full of interest; and on some ocean coasts, as well as on most lake shores, there will be found numerous instances of the minor coastal feat-

¹ The number of excursions suggested may seem excessive; but it is assumed that no one school will be so favorably located as to make it possible to study all of these phenomena in the field.

ures, such as bars, spits, and possibly small deltas. This kind of work may very advantageously be supplemented, or if necessary be replaced, by a study of the admirable charts of the American coast, which are sold at a very slight cost by the U. S. Coast Survey at Washington. Some of these charts should be in every school where physical geography is taught. For those who dwell near the Great Lakes, the charts of the Lake Survey (sold at \$0.20 a sheet) will be found very valuable aids to the study of shore lines.

CHAPTERS XIX. AND XX. — To most students the subjects treated in these chapters are inaccessible, and they must be studied upon maps, models, and photographs. Unfortunately the demand for materials for laboratory instruction in geology and physical geography, has not yet been sufficient to warrant the preparation of cheap illustrative models of such phenomena as these. In schools where modeling is done, many valuable lessons could be taught by having each student illustrate these changes by the actual construction of models; and a well-constructed series would undoubtedly find ready sale. As soon as the rational method of instruction is introduced, and there is a strong demand for new and additional material, it will undoubtedly be supplied. In the meantime it will be necessary for the teacher to make use of the only material that is at hand; namely, maps and photographs. Much can be learned from a carefully selected series of these; and some of the schools will be situated near or among the mountains, so that, in these cases, excursions may be made for the purpose of studying some of the mountain peculiarities. In many parts of New England, in the Catskills, and in the entire Appalachian belt, the opportunity for this kind of illustration is excellent; and if the teacher will take the trouble to look about him, he will find numerous interesting lessons. For instance, along the eastern base of the Appalachians, there exist two sets of mountain ranges, the very ancient series now reduced to low, rounded hills, and the younger, but still old, and relatively high Appalachians. Among the Cordilleras, there is an abundant opportunity for the study of mountains, and in many places of volcanoes also.

CHAPTER XXI. — The teacher will be able to illustrate these features also; for by looking about him, he will find a variety of land forms, and among these will be found illustrations of importance. They may be merely plains or swamps, or they may be mountains. For the teacher who looks with an open eye, there is abundant chance for the discovery of illustrations of the relation between structure and topography. It

would not be necessary to take excursions to every place; but an admirable method is to request the students to visit some of the places and report upon them. This method has been tried with good success, the students being sent out in squads to examine and report upon land or rock peculiarities, at times outside of the regular school hours. There are many photographs and maps which may be used in illustration of this chapter.

CHAPTER XXII.—The teacher will find it possible to expand this subject in connection with the study of history and geography. Indeed, throughout physical geography there are numerous points which could properly be made to serve in the teaching of these subjects. Much good can be done in geographic teaching by showing that, in many cases, features of geographic importance are not arbitrary, but have their origin in physical causes. Most of us have learned that England is a great country, that it manufactures this and that, etc.; but the fundamental reasons for her greatness are not ordinarily presented. We learned to bound Switzerland or France, but did not learn what these boundaries meant. We learned the size, position, and industry of Philadelphia, but did not find out the reasons. If we had been told the causes, the isolated fact would have been more easily retained; for the average mind learns unconnected facts with much less ease than those which are philosophically related.

CHAPTER XXIII.—This chapter is mainly intended to be one of information; and while abundant opportunity exists for laboratory work, it does not seem so essential, or so easily obtained, as in the preceding chapters. Indeed, the teacher who follows the foregoing suggestions will probably find that the main difficulty lies in the fact that too much is suggested.

APPENDIX I.—No part of meteorology is better capable of furnishing illustration by laboratory methods. The various instruments can be placed by the teacher, and the class be taught to make regular observations, just as is done at any meteorological station. These can be plotted upon cross-section paper, to illustrate ranges in temperature, weather changes, etc. By this means each of the more important instruments may be understood, and a knowledge obtained concerning the results of their use. A series of weather maps for successive days can be furnished each student for study, and for statement concerning the conditions and changes illustrated. Much interest in the subject will be aroused by having the weather map posted in some conspicuous place; and each student can be taught to see upon what basis the weather predictions

are made. Indeed, the students may make their own weather maps and weather predictions. Furnished with outline maps of the United States,¹ each student can plot temperature, pressure, wind direction, etc., for various places, from observations which the teacher furnishes from a map. After making one or two of these, the student will be in a position to thoroughly understand weather maps. Let the teacher take a series of weather maps for successive days, and have the class plot upon their maps the conditions there recorded. After two or three have been finished, each member of the class ought to be able to make a fairly close prediction of the general weather conditions of the country for the next day. They might even embody these predictions upon another map. Not only will these methods teach students how to use weather maps, but the mind is put to work imagining and drawing conclusions from a series of facts.

Weather maps are readily obtained free of cost from the United States Weather Bureau, at Washington; and, in some states, a teacher who is willing to maintain voluntary observations may obtain the more common instruments from the State Weather Bureau. A set of the really necessary instruments is not so very expensive, and some, such as the thermometer and barometer, may also be used in the physical laboratory.

APPENDIX II. — There is no better way to teach the student the meaning of the topographic map, than to have him make one of a small area. Moreover, it impresses the meaning of elevations in a way that no other in-door method can do. In the making of models and maps, there is a training in the appreciation of proportion, in constructive imagination, and in the grouping of facts, that is most valuable, and is usually not obtained by the student. No one should be allowed to go through the secondary school without having some development of the "topographic sense." I have known educated people who have lived in a place for several years without having the points of the compass in mind, who have had no idea of the direction to a neighboring place to which they have gone by train or wagon, and whose estimate of distance is simply ridiculous. Particularly is this true of women: for most men, by contact with the outer world, learn by experience what they might easily have been taught in school, while the majority of women get little of this training, even by experience.

¹ Such as those sold by Rand, McNally & Co., of Chicago, and Heath & Co., of Boston, at the rate of a few dollars a thousand.

QUESTIONS UPON THE TEXT.

In the following questions, no attempt is made to include all that could possibly be asked, but rather to ask the most important, and indicate what class of questions seems best calculated to produce the most desirable effect, both in interesting the student, and in drawing from him what he knows. The questions frequently ask for a general view of the subject; and it may often be necessary for the teacher to ask the pupil other questions which shall aid in obtaining a thorough answer. An excellent kind of question, is one calling for more than a mere answer from the text, but rather one in which the student groups things, partly from his own mind, and partly from the book; such, for instance, as asking the application or bearing of a point treated in the book. The questions are arranged under sections corresponding to those of the book, and usually follow the order of presentation of the subject.

CHAPTER I.

THE EARTH AS A PLANET. PAGES 3-22.

Form of the Earth. — Of what is the earth composed? What is its form? What irregularities are there on the surface? What are the differences between the elevation of the land and the depth of the ocean? What is the area of land and water? What is the depth of the atmosphere?

The Solar System. — What are the five classes of members?

The Sun. — How does the sun differ from the other members of the solar system? What does the spectroscope reveal? What are the three parts of the sun? The characteristics of each? What are sun spots? What are the movements of the sun?

The Planets. — What are the important features of Mercury? Of Venus? Of Mars? Of Jupiter? Of Saturn? Of Uranus? Of Neptune?

Asteroids. — What are these?

The Earth. — What reasons have we for believing that the interior is highly heated? What is the probable condition of the interior? What are the movements of the earth? What are the peculiarities of its revolution? What is the cause of the seasons?

The Moon. — What are its movements? What is perigee? Apogee? Why is one side of the moon never seen from the earth? What are the probable conditions on the moon?

Comets, Shooting Stars, and Meteors. — What are comets? How do they move? What is the origin of meteors? Why do they glow?

The Stellar System. — What is the probable number and distance of the stars? How are they arranged? What and where are nebulae?

Symmetry of Solar System. — What points of symmetry are noticed? What are the distances between the members? Illustrate.

The Nebular Hypothesis. — State it.

Verification of the Nebular Hypothesis. — What points are there tending to verify this hypothesis? What is the probability of its truth?

CHAPTER II.

THE ATMOSPHERE. PAGES 23-42.

General Statement. — What variation is there in the density of the air? What gases compose the atmosphere? What is dust in the atmosphere? Water vapor? What is the importance of the atmosphere?

Light. — What is the source of our light? Of what is white light composed? What is diffusion of light? Selective scattering? What effect upon light is produced by dust? What is the cause for the sunset color? What is reflection? Give illustration. What is mirage? Looming? Refraction? What is the cause of the rainbow? What is the halo? The corona? What is absorption of light? Why are bodies transparent, translucent, and opaque? Why are some objects colored?

Electricity and Magnetism. — What are the indications of terrestrial magnetism? How is atmospheric electricity made apparent? What is lightning? Thunder? Heat lightning?

Heat. — What is the source of heat? How do different bodies behave toward it? What interferes with its passage through the atmosphere? Why does the ocean surface remain relatively cool? What is latent heat? Why does the land become warmer than the ocean? How is the atmosphere warmed? What is radiation? Conduction?

Convection? What is the importance of convection? What are the differences in heat effect and their results? What is the effect of rotation on the temperature of the air? Of revolution? How does this differ in various parts of the earth? What are the reasons for the short, cold days of the temperate latitude winter? What is the normal variation or range in temperature during the year? How does this differ in the several zones, — tropical, temperate, and arctic?

Moisture. — What is evaporation? What is saturated air? In what places is the air naturally driest? Why do winds favor evaporation? How does temperature effect evaporation? What is absolute humidity? Relative humidity? Dew-point? What is the effect upon humidity caused by oceans? By tropical heat? By elevation? By descent of air from higher altitudes? By the passage of air currents from warm to cold regions? From cold to warm? By the rising of air? What are the effects of variations in humidity?

Pressure. — In what two ways does the air pressure vary?

Effect of Gravity. — What is its effect upon the atmosphere?

Effect of Rotation. — What important effect upon moving bodies of air and water is produced by the earth's rotation? State the reason.

CHAPTER III.

DISTRIBUTION OF TEMPERATURE. PAGES 43-67.

General Statement. — What is the normal distribution of temperature from equator to pole? What are the normal seasonal and daily ranges or curves? How are they interfered with?

Effect of Atmospheric Movements. — In what ways do the atmospheric movements modify the temperature?

Influence of Oceans. — Why are the ocean temperatures more equable than those of the land? What is the effect of the oceanic circulation in this respect? How does the temperature change from seashore to interior? From tropical to arctic regions?

Effect of Topography. — How does the temperature on the hills differ from that of the valleys? How does it differ on the north and south sides of hills? Why are mountain tops colder than lowlands? What does this show as to the behavior of heat?

Seasonal Temperature Range. — What is an isotherm? Why are isothermal lines not parallel to the latitude? What is the normal temper-

ature range? How is this shown on the isothermal charts? What do the curves show? How does the range differ in various places, — ocean, land, and different latitudes? Why do not the highest parts of the curve coincide with midsummer? The lowest with midwinter? In what ways is the normal curve interfered with?

Isothermal Charts. — Why are the isotherms of the southern hemisphere more regular than those of the northern? Why is the heat equator north of the geographic equator? What is the effect of the Gulf Stream? The Labrador current? How does the temperature distribution of the west coast differ from that of the east? Why? Why is the heat equator so far north in July? Why is it farther north in the Atlantic than in the Pacific? Why is the deflecting influence of the Gulf Stream greater in January than in July? Why do the isothermal lines change in position more in the northern than in the southern hemisphere? Where are the coldest places on the earth? Where is the cold pole? Where are the greatest seasonal ranges in the United States? The least? Why? Why are deserts places of great temperature range? What influence of topography is shown on the chart of New York?

Daily Temperature Curve. — What is the normal daily range? When do the coldest and warmest times come? Why? How does the curve differ in different places? According to season? By accidental interruptions?

Temperature Ranges. — How closely do the isotherms give the real temperature conditions? Illustrate by San Francisco. Where are the lowest and highest temperatures found? The greatest ranges? Where are the greatest and least ranges in the United States? Give an example of rapid change. Contrast the range of Key West and Montana. Give an example of great daily temperature range.

Earth Temperatures. — What is the normal change in earth temperature? In the tropical regions? The temperate? The arctic? How does the temperature of the surface compare with that of the air?

CHAPTER IV.

GENERAL CIRCULATION OF THE ATMOSPHERE. PAGES 68-84.

General Statement. — Illustrate mobility of the air by its action on deserts. Compare with the effect of a stove. How may this comparison be extended to the atmospheric circulation? What are the four

principal parts to this circulation? In what ways are these changes registered by the barometer? What is a barometric gradient?

Classification of the Winds.—Give the classification of the winds. What are the planetary or permanent winds?

Planetary or Permanent Winds: Trade Winds.—What are the trade winds? How and why do they move? Where are they best developed? Why do they produce deserts? Why do they often cause very rainy belts? How can the same wind produce these two opposite effects?

Doldrum Belt.—What are the doldrums? Their characteristics?

Anti-trade Winds.—In what direction do they move? How do we know of their existence?

Horse Latitude Winds.—Where does the air come from? What are the characteristics of the belt?

Prevailing Westerlies.—What is the circumpolar whirl? How do we know the permanency of these winds in the upper air? Of what value are they in the southern hemisphere? Why not also in the northern?

Periodical Winds.—What are these?

Seasonal Winds.—Where is the change of the season most noticeable? What effects are produced in the atmospheric circulation near the tropics? What is the seasonal effect on the land? What is the monsoon? Where are monsoons found? How is their influence noticed in the United States? How do the winds of Greenland show the influence of the season? What is the effect of friction between wind and land?

Diurnal Winds: Sea and Land Breezes.—What is the cause of the sea breeze? When does it come? What are its effects? What is the land breeze? What do these winds resemble? What is the effect of the sea breeze in the trade-wind belt? What is the general effect of the day-time heat on the winds of the land? What are lake breezes?

Mountain and Valley Breezes.—Describe the valley breeze as to cause and effect. The mountain breeze. Why are the former more violent than the latter? Where are these breezes noticed outside of mountains?

Eclipse and Tidal Breezes.—What are these?

Irregular Winds.—How do they differ from the preceding?

Accidental Winds.—What is the landslide or avalanche blast? What are the volcanic winds? The waterfall breeze?

The Nature of Winds.—What is the real nature of the wind? What causes introduce a vertical movement? What are the possible uses of the internal work of the wind?

CHAPTER V.

STORMS. PAGES 85-106.

Cyclonic Storms. — What is a storm? What are some of the causes of storms? What are the two kinds of cyclonic storms?

Hurricanes: Description. — Where do the hurricanes begin? The typhoons? What changes are noticed as the storm nears and passes over a place? What is the eye of a storm? How is the air moving in the storm?

Effects. — What is their effect upon vessels? Upon the coast? State some instances.

Path. — What is the natural path in the North Atlantic? How do they sometimes diverge from this? What is their path in the Pacific? South of the equator? What is their size? Where are they most violent?

Time of Occurrence. — When are they most common in the northern hemisphere? In the southern? What is the line storm?

Cause. — What are the facts to be accounted for? Why may we expect that the heat of the tropics is the cause for their beginning? What would account for the whirling? What reason is there for the greater influence of right-hand deflection in certain seasons? Why should they be confined to the ocean? What is the effect of condensation of water vapor? Why do the storms lose energy when they have passed beyond the tropics? What is the explanation of the path? Describe the hurricane. State its cause briefly and clearly.

Temperate Latitude Cyclones: Resemblance to Hurricanes. — How do they resemble hurricanes?

Differences from Hurricanes. — How do they differ in general behavior? In time and place of development? In path? What is the usual path?

Effects. — Where do they occur? What are their effects in the United States?

Winds. — How do these vary? What changes occur as the storm passes? What is the sirocco? The foehn? The chinook? The blizzard? The norther?

Anticyclones. — What is their cause? What are cold waves? What are the accompanying conditions of winds?

Cause. — What was the former theory? What objections can be urged to it? State a possible explanation. What is the reason for their paths?

Secondary Storms: Thunderstorms. — Where do they occur? Under what conditions? What is the cause for the thunder cloud? Its form

and features? What is their relation to cyclonic storms? Their path? What is a cloud burst? Describe and discuss the thunderstorm.

Tornadoes and Waterspouts.—What are the form and characteristic features of the tornado? Their effects? The area covered and time occupied? In what respect do they resemble thunderstorms? What is the cause? What is a waterspout?

CHAPTER VI.

THE MOISTURE OF THE ATMOSPHERE. PAGES 107-123.

Dew.—What is the cause of "sweat" on a pitcher of ice water? How does this resemble dew formation? At what temperature and time will this occur? What conditions especially favor the formation of dew? Why does dew occur more readily in valleys than on hilltops? What is the main cause for dew? What other causes also aid?

Frost.—What is frost? What prevents it?

Fog.—What is fog? What is the cause for ocean fog? What is valley fog? In what other ways may fog be caused? What is the relation of dust to fog?

Haze.—What is haze? Its cause?

Mist.—What is mist?

Clouds.—Of what are clouds composed? Under what condition are they formed? Give the classification of clouds. Describe the cirrus; the cirro-stratus; cirro-cumulus; cumulus; cumulo-stratus; stratus; nimbus.

Rain.—What is the cause of the drop? Under what conditions is rain caused? What relation does it bear to clouds?

Snow.—What is snow? The difference between snow and rain?

Hail.—What is hail?

Distribution of Rainfall in the World.—What do we mean by rainfall? Why are there differences according to altitude and latitude? What is the cause for variation in tropical regions? What is the effect of steeply rising mountains? What are the two main causes for deserts? What are the rainfall peculiarities within the belt of calms? How does the rainfall vary from coast to interior?

Distribution of Rainfall in the United States.—What are the causes for the heavy rains of the Texas and Florida coasts? For the differences between the east and west coasts? What is the effect of the high western mountains upon the rainfall of the western half of the country?

Distribution of Snowfall. — Where does snow fall? Where are glaciers produced?

Seasonal Distribution of Rainfall. — What is the effect of the migration of the belt of calms? How do the monsoons affect the seasonal rainfall? What is the reason for the winter rains of Washington and Oregon? For the irregularities of rainfall in the east?

Irregularities of Rainfall. — What is the normal rainfall? How does it sometimes vary from this? What are the effects of heavy downpours?

CHAPTER VII.

WEATHER AND CLIMATE. PAGES 124-134.

Weather. — What is weather? Climate?

Tropical and Arctic. — What are the weather conditions of the belt of calms? Of the trade-wind belts? Of the polar regions?

Temperate Latitude Weather. — What are the weather conditions on the northern Pacific coast? In the mountains east of this? In the deserts between the mountains? On the plains of Dakota, etc.? On the more southern plains? In the southern coastal states? In the northern central states? What is the cause for the droughts? What are the weather conditions of the northeastern states? What are the winter conditions in this belt? The summer climate? What are the typical weather conditions in temperate latitudes? How do those described differ in Europe? In the southern hemisphere?

Climate. — What are the climatic belts? Their subdivisions?

Tropical Climate. — What is the general climatic condition? The difference between the ocean and the land? The doldrum and trade-wind belts? What are the differences in rainfall? What climatic peculiarities are caused by the monsoon condition of India?

Temperate Climate. — What are the characteristics of the climate of this belt? What are its subdivisions? What is the climate of the western coasts? Of the eastern coasts? The interior climate? Of mountains? Of the inter-montane district. State the climatic differences noticed on the parallel of 50° N.

Arctic Climate. — What are its characteristics?

Minor Variations. — What are some of these?

Changes in Climate. — What two classes of evidence point to climatic change? What is the supposed thirty-six-year cycle? What is the

geological evidence of former differences in climate? What recent geological changes are recorded in the United States? What are the possible explanations of these changes?

-CHAPTER VIII.

GEOGRAPHIC DISTRIBUTION OF ANIMALS AND PLANTS. PAGES 135-148.

General Statement.—What are the life zones? What kinds of life occur in the several zones? What are the differences between the life in fresh and salt water?

The Ocean.—What causes the wide distribution of ocean life? What is the effect of temperature on distribution? Where in the ocean are plants unable to live? Under what conditions do they especially thrive? What is the difference between the tropical and northern animals?

Fresh Water.—What are land-locked animals? What forms of life are found in fresh water? What is the effect of change to salt lake?

The Land:—Effect of Temperature and Moisture.—What is the effect of temperature? What is the effect of arctic cold on the animals? On the plants? Of the cold of high temperate latitudes? What is the influence of altitude? What changes in vegetation are noticed in ascending high mountains? How may this vary on the opposite sides of a mountain? What are the effects of aridity? Of great moisture?

Plant and Animal Habits.—How do the seeds effect the distribution of plants? What animal habits influence distribution?

Life Zones.—What are the great life zones and their subdivisions? How do the continental zones resemble one another? How do they differ? What do these differences and resemblances show? How is this illustrated by oceanic islands? In the Bermudas? In New Zealand? The East Indies? Australia?

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